

IN THIS NUMBER:
FULL TEXT OF MR. NIKOLA TESLA'S LONDON LECTURE.

THE ELECTRICAL WORLD

AN ILLUSTRATED WEEKLY REVIEW
OF CURRENT Progress IN Electricity AND ITS PRACTICAL APPLICATIONS

VOL. XIX, NO. 19.
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NEW YORK: 167-170 Times Building. Published every Saturday.
MAY 7, 1892.
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 167-176 TIMES BUILDING, NEW YORK.
 Telephone Call: Cortlandt 924. Cable Address: "Electrical," New York.

New England Office, 28 Hathaway Building, Boston.
 Western Office, 465 The Rookery, Chicago.
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VOL. XIX. NEW YORK, MAY 7, 1892. NO. 19.

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American Exhibits at the Crystal Palace. In view of the fact that Englishmen so often speak in complimentary ways about what the Americans do in electrical engineering, it may be of interest to Americans, and of instruction to Englishmen, to note here a report received from a private correspondent to the effect that if the American exhibits were taken out of the Crystal Palace Exhibition there would be comparatively little of interest left. Under American exhibits are meant those that originally emanated from this side, although now in the hands of English companies. It will be remembered that the same was also true, though perhaps in a less degree, of the electrical exhibits at the Paris Universal Exhibition of 1889, in which the American exhibits not only covered a large part of the space devoted to this branch, but included without doubt the most novel and interesting electrical exhibits both to the general public and the electrician.

High Potential Phenomena. WE are pleased to see that a number of able experimenters are now making researches in the field of high potential phenomena about which so little was known only a short time ago, and which appears to open up such a new and interesting branch of electrical engineering. It is also a great satisfaction to notice the spirit of the experimenters in letting the public enjoy the results of their private researches by contributing descriptions of their work and results to the current electrical literature. As in some other new fields, recent experiments seem to show us that less was known about the behavior of high potential currents and their action on insulating materials

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than was thought to be known. A table published many years ago embodying the results of experiments with striking distances made with a high potential battery was for a long time used as a sort of standard and was considered by many to show a reliable law. We now find out, however, that the law, if there is any universal law at all, is quite different from what it was supposed to be. The instructive experiments described by Mr. Skinner, of the Westinghouse company, in another column, accompanied by some very interesting cuts, are of the kind which will doubtless lead to a clearer understanding of this interesting field.

Efficiency of the Lauff-We are glad to be able to announce that some of the results of the official test of the Lauffen-Frankfort transmission of power plant have at last been made public, although the details, we regret to say, are still wanting. It appears from this report that the efficiency, measured from the turbine shaft at Lauffen to the secondary terminals of the transformers in Frankfort, was, in round numbers, 75 per cent. The loss of 25 per cent. was distributed about as follows: Eight per cent. in the dynamos, 11 per cent. in the line, and three to four per cent. in each of the transformers. It will be noticed from this that the figures of the efficiency, which we published some months ago, received from private sources, were so near to the correct results that the present reports merely confirm them definitely, but add nothing new. There is still a question of how the efficiency will fall for smaller loads, in which case the charging of the line becomes a more important matter. In large plants, however, it is the efficiency at full load which is of importance, and not that at small loads. An efficiency of 75 per cent. is certainly excellent for a transmission of over 100 miles through wires which, to all appearances, are not larger than the usual telegraph wires.

Qualification of Faraday's Law. IN another column a contributor appears to question the validity of Faraday's law regarding the equivalents between a current and the metal deposited by the current. It ought to be understood, however, that it is really not Faraday's law which is in question as much as the way in which it is often stated by others. It is well known, for instance, that the amount of copper deposited per ampere per second may be double as much in one solution as in another, depending on the chemical combination in which the copper is held in that solution. This fact is well known and is stated in text books, which are clear and complete. It would appear, therefore, that, rather than to shake the foundation of our knowledge of electricity by questioning the validity of one of the fundamental laws, this law should be qualified or stated more clearly so as to cover all cases. The language often used in giving this law in books may not be sufficiently exact, but the law itself when properly understood would not have stood unquestioned so long if it were not correct. There is another law which should not be forgotten, namely, "Don't monkey with a buzz saw," which is good advice to persons who attempt to overthrow well established laws.

Recent Progress in Electrical Industries. IT may seem almost superfluous to give figures to substantiate the statements that have been made about the almost abnormal growth of the electrical industries; but for the benefit of the skeptical, as well as for others interested in the actual figures, we have compiled the following, which fully substantiates the claims made regarding this growth. From the reports of the various Secretaries of State it appears that in the last eight months 284 new central lighting stations were incorporated, representing a capital of \$100,192,000; 133 new general electrical trades, representing a capital of \$67,946,500, and 105 new street railways, representing a capital of \$61,100,800, not all of which, however, were electrical, although we have no doubt it will be found from detailed reports that by far the larger part of them were, as it is difficult to conceive that at the present time anything but electric and cable roads would be projected. The grand total of all these for the eight months is \$229,239,700. From a reliable contemporary it appears, furthermore, that the Westinghouse Electric Company is said to have three months' business on hand and is increasing its facilities; the Thomson-Houston Electric Company has unfilled orders for nearly 2,000 motors; during the past week the West End Street Railway Company has ordered 104 new motors; orders were received from New Orleans and St. Paul, each for 60 new motors; the Thomson-Houston Company has part of the contract to furnish the equipment for the Interstate Railroad of Providence. It is furthermore claimed that the combination of the Edison and Thomson-Houston interests will result in lower prices to customers on all apparatus, but that great care will be taken to avoid making unprofitable contracts.

No Right to Tax Patent Rights. A CASE has just been decided in Pittsburgh which is of importance to electrical manufacturers. Although it has reference to Pennsylvania State laws it nevertheless has some bearing in the other States as well, as it appears to be a question of interfering with rights granted by Congress. The question was whether the State had the right to tax the Westinghouse company. The tax law exempts companies organized exclusively for manufacturing purposes, but the officers of the State claimed that the company has in its char-

ter a great variety of powers besides those belonging strictly to a manufacturing corporation, and was therefore taxed upon its whole capital stock. The company claimed that its sole business was the manufacture of electrical apparatus. Regarding this point Judge McPherson decided that the company, notwithstanding the varied powers conferred by its charter, was nevertheless organized exclusively for manufacturing purposes, which decision seems to be eminently just. The company has other powers than those of manufacturing conferred by its charter, but it does not use them. The question also came up as to the right to be taxed for stock invested in patents. A large part of the capital stock of that company is invested in this manner, and it claims that this cannot lawfully be taxed by the State in any event. The court sustained the contention of the company's counsel, and held that the right to tax patent rights does not exist in the State, "as a tax upon the right itself we think it cannot possibly be supported, because it restricts and interferes with a right granted by Congress in the exercise of the power committed to the government of the United States by the Federal Constitution. The tax is not only derogatory from the dignity, but subversive of the powers of the government and repugnant to its paramount sovereignty." The court expressly states, however, that the opinion is restricted to the intangible rights existing in the patents, and does not extend to tangible articles manufactured under patent rights. The decision in each of the cases was entirely in favor of the company.

Tesla's London Lecture. AT last the much talked of lecture of Mr. Tesla, held in London in February, has reached this side. In order to give Americans the benefit of it, we print it in full in this issue. It forms a very interesting addition to his first paper, read in New York a year ago, and also printed in full in THE ELECTRICAL WORLD, July 11, 1891. To comment on it here would be quite impossible for any one who has not himself worked in this new and strange field which Mr. Tesla was unquestionably the first to enter and is at present still the sole explorer. We can only read with silent admiration the descriptions of his very interesting experiments and of his strange, dream-like prophecies of the future which his researches lead him to predict and which, coming from any one less distinguished, would doubtless be laughed at as wild speculations. One cannot help admiring his courage, modesty, clear-sightedness and persistency in working as he does in this strange field, in which it seems as though the obstacles were almost insurmountable. The fact that these currents defy the resistance of almost all our known methods of insulation would in itself seem sufficient to discourage most experimenters. Being sure of the correctness of one of his chief objects, namely, that there must be some way of artificially producing cheap and economic light by methods radically different from the present, he proceeded first to find it, then to overcome the difficulties encountered and to make it practical. In general his lecture is of scientific interest, but much of it can be read with interest by any electrician, and will give him a good idea of the nature of this new field of research. This present lecture is more in the nature of a continuation of his first one, rather than a repetition, as he appears to assume a knowledge of the former paper, although this assumption is not essential. A large portion is devoted to a detailed description of his experiments and of his apparatus, intended more particularly for those who wish to reproduce them; other portions, to some of the more or less definite conclusions which he has arrived at; still others, to interesting predictions which his researches justify him to make. He credits Crookes with having given him his first idea, and throughout his whole lecture, with becoming modesty, he appears to forget Tesla, in his interest in the experiments. The interesting nature of this field and of his predictions will be seen from the following extracts: He speaks of the possibility of obtaining light effects without the use of any vessel whatsoever, with air at ordinary pressure; he advocates oil as one of the best insulators, and speaks of distribution at 100,000 volts as "an easy matter," and practicable to even 1,000 miles; with his sensitive rotating brush discharge he thinks that transatlantic telegraphy will be possible at any speed; he speaks of 30,000 vibrations per second as "few," and of air as being "highly conducting" in this new field; of running lamps and motors, not only with one wire, but also with no wire at all, and at considerable distances; this he follows by predicting that we shall have no need to transmit power at all, and it is only a question of time when we will be able to obtain it, extract it, as it were, from any point in the universe; he believes it quite possible to obtain at least twenty times the efficiency of our present incandescent lamp, and shows the importance of the incandescence of the gas surrounding the button in his lamp, the button itself being merely a "necessary evil. High potentials such as he uses he does not consider dangerous. He speaks of a system in which the metal pipes are the insulators and the gas in them the conductors. He describes a cable with which telephoning across the Atlantic may become possible, but adds that it will not be required, as ere long "intelligence will be transmitted without wires through the earth." He has been led to believe that light and heat effects in his experiments are proportional to the product of the frequency and the square of the potential, and suggests the possibility of using frequencies of several millions per second!

Wiring Table for Secondary Alternating Current Circuits.

BY H. W. FRUND.

In alternating current service it has been found by practical experience that we cannot estimate the losses in wiring by figuring from the dead resistance of the wire alone, for owing to the alternations of the current there is spurious inductive resistance set up in the wire which acts in a manner different to that of the constant current, tending to increase the loss to a slight extent. The following formula is arranged to cover the difference due to ohmic resistance and inductive resistance. This formula can be used for direct current work exactly the same as with alternating with the exception that the constant must be changed to 10 for direct currents in place of 13 for alternating currents.

The formula with which the accompanying table has been prepared is as follows:

$$\frac{C \times L \times K}{V} = \text{Circular mils area.}$$

C = current in amperes.

L = total length of wire contained in both legs of circuit.

K = constant of 13, equivalent in inductive resistance to one mil-foot of commercial copper.

V = volts loss.

SECONDARY WIRING TABLE FOR 100 VOLT, 16 C. P. LAMPS, WITH .6 OF AN AMPERE PER LAMP; LOSS TWO VOLTS.

No. of lamps.	Distance in feet to centre of distribution.																			B & S gauge numbers.
	20'	25'	30'	35'	40'	45'	50'	60'	70'	80'	90'	100'	120'	140'	160'	180'	200'			
1	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	
2	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	
3	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	
4	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	
5	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	
6	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	
7	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	
8	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	
9	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	
10	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	
12	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	
14	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	
16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	
18	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	
20	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	
22	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	
24	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	
25	14	14	14	12	12	12	10	10	10	8	8	8	6	6	6	6	6	4	4	

Some High Potential Phenomena.

BY C. E. SKINNER.

A series of experiments and tests have been in progress at the laboratory of the Westinghouse Electric and Manufacturing Company, with a view of determining the characteristics and insulating properties of certain materials when subjected to high potential differences. Some of the phenomena and results which have been noted may prove of general interest in view of the present activity in this line of work.

Several transformers connected in series are arranged to give any required difference of potential up to 35,000 or 40,000 volts. A Cardew voltmeter is used in the low potential circuit, and the final E. M. F. is determined by ratio of conversion.

Considerable experimenting has been done to determine the striking distance of different electromotive forces in air with different electrodes. It is not possible to give a curve for striking distances that will be more than approximately correct unless the greatest precautions are taken in obtaining readings. The striking distance depends upon a great many conditions, a change in any one of which will change the striking distance for the same indicated E. M.

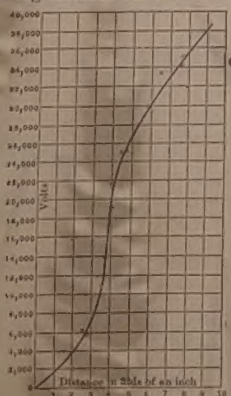


FIG. 1.—STRIKING DISTANCE BETWEEN TWO 90-DEGREE POINTS IN MELTED PARAFFINE AT 57 DEGREES C.

F. Some of the most important of these conditions are the following: Very slight burning or roughening of the points or surfaces used; dust or lint on them; length of time of application of E. M. F.; change in capacity of conductors or electrodes sufficient to bring in condenser effect (the latter may cause a spark across the air gap and current will then follow); and the use of armatures giving different E. M. F. curves. The striking distance and the power to break down insulation of any alternating current depends upon the maximum E. M. F. reached, and not upon the mean as read by a Cardew voltmeter. The number of alternations per minute is a very important element. There is often a change in results for which there is no apparent reason, but which may be due to the phase of the E. M. F.

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at the time of closing the switch. Temperature, humidity and air currents also have their effect, but these are not so marked as the other influences named.

With an armature giving very nearly a sine curve and 10,000 alternations per minute the following results have been found. The potential differences given in this table are those indicated by a Cardew voltmeter:

Kind of Electrodes used:	E. M. F.	Distance in 30ths of an inch.
Two 1/2 in. polished brass balls.....	35,000	27
Two 2 in. brass plates, rounded edges.....	35,000	60
Two 1/2 in. brass rods turned to 90 degrees.....	35,300	77
Points, points slightly rounded.....	35,500	48
Ball and plate.....	35,000	77
Point and plate.....	35,200	63
Ball and point.....	35,000	53
Two 1/16 in. platinum balls.....	35,000	66
Two pin points.....	35,000	66

Curves for striking distances in various kinds of liquid

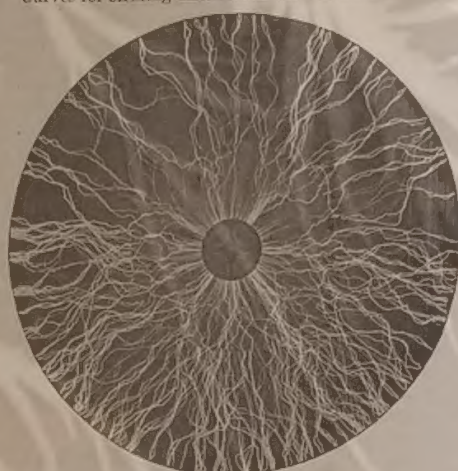


FIG. 2.—35,000-VOLT DISCHARGE OVER THE SURFACE OF A GLASS DISC, 10 INCHES IN DIAMETER.

insulators have been found. Here again great care must be taken to have the conditions the same or the results will vary. Impurities, however slight, mechanical stirring of the liquid and the oxidation of the insulating material are some important conditions which affect the results in addition to those already enumerated for striking distances in air. The temperature is here an important item and should not be overlooked. The curve, Fig. 1, was obtained for the striking distances in melted paraffine at 57 degrees C. with two 90 degree points used as electrodes.

The peculiar network of fiery streamers spreading over the surface of a solid dielectric when placed between the high potential terminals has already been described by other observers. The accompanying photographs show this effect when a potential difference of 35,000 volts was employed with terminals and dielectric arranged to give as even a distribution of streamers as possible. The lower terminal is a brass disc 4 1/2 inches in diameter. Upon this is placed a circular disc of glass or mica. The upper terminal is a toothed wheel 1 1/2 inches in diameter above the plate. The connection to the upper terminal is by means of a fine copper wire. Fig. 2 was obtained when a plate of glass 10 inches in diameter and .005 inch thick was used as the dielectric. The spaces between the rim and spokes of the wheel and immediately over the lower disc, outside of the wheel, are filled with a violet light resembling a brush discharge. There are well defined bands inside of



FIG. 3.—35,000-VOLT DISCHARGE OVER THE SURFACE OF A MICA DISC 10 INCHES IN DIAMETER.

the wheel where the action is neutral. From the teeth of the wheel long streamers run over the edge of the glass and back to the lower disc.

The outline of the lower disc can readily be made out from the ends of the streamers which are seen through the glass. Fig. 3 shows the effect obtained by using a disc of mica of the same diameter as the glass and .018 inch thick. The portion of the streamers returning to the lower disc cannot be followed so easily in Fig. 3 as in Fig. 2 on account of the slight opacity of the mica used. The streamers are constantly changing their paths, giving the appearance of

an animated network of fiery threads. The time of exposure for these photographs was in each case about one-tenth of a second. A shorter exposure shows fewer streamers and it is possible that for each alternation there is but one current used is very small. Two distinct sounds accompany this discharge, one a loud crackling sound, the other the peculiar hum due to the alternating current dynamo. Beautiful brush discharges can be obtained by removing the dielectric and separating the terminals just beyond the striking distance for the E. M. F. used.

One terminal of the 35,000-volt circuit given one turn around an incandescent lamp bulb fills the lamp with a bluish light and at the same time violently agitates the filament, which is usually broken after a few seconds.

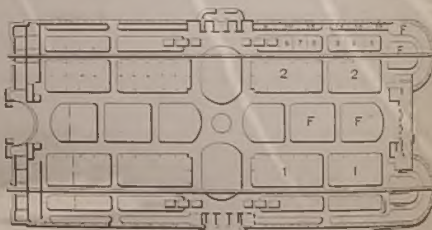
The static induction of one terminal upon the other may be shown by winding a helix of fine copper wire on the outside of a glass tube and placing a similar helix upon the inside. On connecting the high potential terminals to the two coils, the tube is filled with bluish light and every few seconds a discharge takes place from one spiral to the other through four or five inches of air around the end of the tube. A few plates of glass built up with tinfoil as a condenser give the same phenomena with increased intensity. After a few seconds the glass breaks down, being either pierced by the current or cracked by the intense heat of the discharge. Plates of glass have been found with deep furrows in one side as if small pieces had been forcibly chipped out. A strong odor of ozone accompanies all these luminous effects.

Apparatus is now in use giving a potential difference of over 100,000 volts with various frequencies. Some preliminary work with this apparatus shows that liquid insulators are more effective with high than with low frequencies.

Allotment of Space for the World's Fair in the Electricity Building.

Professor Barrett, chief of the Department of Electricity, has allotted the space in the Electric Building to the various countries that have signified an intention of making displays, and in nearly every case the space allotted has been accepted, and arrangements are already being made for the installation of the exhibits.

The spaces given to the different countries are as follows, the letters or figures referring to the accompanying cut: F, France, 16,000 square feet; 1, Germany, 20,000; 2, Eng-



ARRANGEMENT OF FOREIGN ELECTRICAL EXHIBITS AT THE WORLD'S FAIR.

land, 20,000; 3, Austria, 1,100; 4, Switzerland, 1,100; 5, Belgium, 1,100; 6, Mexico, 500; 7, Spain, 500; 8, Italy 500; 9, Russia, 440; 10, Holland, 440; 11, Denmark, 440; 12, Norway, 440; 13, Sweden, 440.

There was a slight misunderstanding, however, as to the position and amount of space which France should occupy. When it was found that only 6,000 square feet of space had been reserved for France, while both Germany and England had been allowed 20,000 square feet, there was considerable feeling on the part of the French in regard to the matter, and they claimed that the space was entirely inadequate for their display. It was explained that the English and German exhibits would consist of heavy machines while that of France would be, for the most part, testing instruments, and also that France had been given a wall space while Germany had not. A compromise was finally agreed upon, and two valuable stands in the centre of the north end of the building, each covering 5,000 square feet, were reserved for France; these are marked F in the diagram.

The space reserved for the German exhibits is in two sections, each marked 1 in the diagram. Germany will make its display of heavy dynamos and motors to a great extent, and especially apparatus for the transmission of power on a large scale. It is said that there will be at least one 1,000-h. p. motor and one 1,500-h. p. generator in the exhibit. There will also be a number of highly finished and powerful search lights, superior to those now manufactured in this country. The Germans lead in electro-deposition, and a fine exhibit in that line is expected.

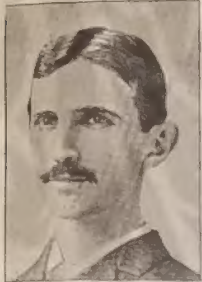
The English display will be somewhat similar to that of Germany, in that it will consist chiefly of heavy machinery. One of the features will be the submarine cable work and the process of manufacturing and testing the cables will be shown, including model ships laying them. The English space is marked 2 in the diagram.

France will contest with Belgium, Sweden, Denmark, Italy, Holland, Norway, Spain and Austria for the honor of displaying the most perfect testing apparatus, including meters and all kinds of fine measuring instruments. The French display will also include some powerful search

Experiments with Alternate Currents of High Potential and High Frequency.*

BY NIKOLA TESLA.

I cannot find words to express how deeply I feel the honor of addressing some of the foremost thinkers of the present time, and so many able scientific men, engineers and electricians, of the country greatest in scientific achievements.



NIKOLA TESLA.

The results which I have the honor to present before such a gathering I cannot call my own. There are among you not a few who can lay better claim than myself on any feature of merit which this work may contain. I need not mention many names which are world-known—names of those among you who are recognized as the leaders in this enchanting science; but one, at least, I must mention—a name which could not be omitted in a demonstration of this kind. It is a name associated with the most beautiful invention ever made: it is Crookes!

When I was at college, a good time ago, I read, in a translation (for then I was not familiar with your magnificent language), the description of his experiments on radiant matter. I read it only once in my life—that time—yet every detail about that charming work I can remember this day. Few are the books, let me say, which can make such an impression upon the mind of a student.

But if, on the present occasion, I mention this name as one of many your institution can boast of, it is because I have more than one reason to do so. For what I have to tell you and to show you this evening concerns, in a large measure, that same vague world which Professor Crookes has so ably explored; and, more than this, when I trace back the mental process which led me to these advances—which even by myself cannot be considered trifling, since they are so appreciated by you—I believe that their real origin, that which started me to work in this direction, and brought me to them, after a long period of constant thought, was that fascinating little book which I read many years ago.

And now that I have made a feeble effort to express my homage and acknowledge my indebtedness to him and others among you, I will make a second effort, which I hope you will not find so feeble as the first, to entertain you.

Give me leave to introduce the subject in a few words. A short time ago I had the honor to bring before our American Institute of Electrical Engineers some results then arrived at by me in a novel line of work. I need not assure you that the many evidences which I have received that English scientific men and engineers were interested in this work have been for me a great reward and encouragement. I will not dwell upon the experiments already described, except with the view of completing, or more clearly expressing, some ideas advanced by me before, and also with the view of rendering the study here presented self-contained, and my remarks on the subject of this evening's lecture consistent.

This investigation, then, it goes without saying, deals with alternating currents, and to be more precise, with alternating currents of high potential and high frequency. Just in how much a very high frequency is essential for the production of the results presented is a question which, even with my present experience, would embarrass me to answer. Some of the experiments may be performed with low frequencies; but very high frequencies are desirable, not only on account of the many effects secured by their use, but also as a convenient means of obtaining, in the induction apparatus employed, the high potentials, which in their turn are necessary to the demonstration of most of the experiments here contemplated.

Of the various branches of electrical investigation, perhaps the most interesting and immediately the most promising is that dealing with alternating currents. The progress in this branch of applied science has been so great in recent years that it justifies the most sanguine hopes. Hardly have we become familiar with one fact, when novel experiences are met with and new avenues of research are opened. Even at this hour possibilities not dreamed of before are, by the use of these currents, partly realized. As in nature all is ebb and tide, all is wave motion, so it seems that in all branches of industry alternating currents—electric wave motion—will have the sway.

One reason, perhaps, why this branch of science is being so rapidly developed is to be found in the interest which is attached to its experimental study. We wind a simple ring of iron with coils; we establish the connections to the generator, and with wonder and delight we note the effects of strange forces which we bring into play, which allow us to transform, to transmit and direct energy at will. We arrange the circuits properly, and we see the mass of iron and wires behave as though it were endowed with life, spinning a heavy armature, through invisible connections, with great speed and power—with the energy possibly conveyed from a great distance. We observe how the energy of an alternating current traversing the wire manifests itself—not so much in the wire as in the surrounding space—in the most surprising manner, taking the forms of heat, light, mechanical energy, and, most surprising of all, even chemical affinity. All these observations fascinate us, and fill us with an intense desire to know more about the nature of these phenomena. Each day we go to our work in the hope of discovering,—in the hope that some one, no matter who, may find a solution of one of the pending great problems,—and each succeeding day we return to our task with renewed ardor; and even if we are unsuccessful, our work has not been in vain, for in these strivings, in these efforts, we have found hours of untold pleasure, and we have directed our energies to the benefit of mankind.

We may take—at random, if you choose—any of the many experiments which may be performed with alternating currents; a few of which only, and by no means the most striking, form the subject of this evening's demonstration; they are all equally interesting, equally inciting to thought.

Here is a simple glass tube from which the air has been

*A lecture delivered before the Institution of Electrical Engineers (London) Feb. 3, 1892.

†For Mr. Tesla's American lecture on this subject see THE ELECTRICAL WORLD of July 11, 1891; and for a report of his French lecture see THE ELECTRICAL WORLD of March 26, 1892.

partially exhausted. I take hold of it; I bring my body in contact with a wire conveying alternating currents of high potential, and the tube in my hand is brilliantly lighted. In whatever position I may put it, wherever I may move it in space, as far as I can reach, its soft, pleasing light persists with undiminished brightness.

Here is an exhausted bulb suspended from a single wire. Standing on an insulated support, I grasp it, and a platinum button mounted in it is brought to vivid incandescence.

Here, attached to a leading wire, is another bulb, which, as I touch its metallic socket, is filled with magnificent colors of phosphorescent light.

Here still another, which by my fingers' touch casts a shadow—the Crookes shadow, of the stem inside of it.

Here, again, insulated as I stand on this platform, I bring my body in contact with one of the terminals of the secondary of this induction coil—with the end of a wire many miles long—and you see streams of light break forth from its distant end, which is set in violent vibration.

Here, once more, I attach these two plates of wire gauze to the terminals of the coil, I set them a distance apart, and I set the coil to work. You may see a small spark pass between the plates. I insert a thick plate of one of the best dielectrics between them, and instead of rendering altogether impossible, as we are used to expect, I aid the passage of the discharge, which, as I insert the plate, merely changes in appearance and assumes the form of luminous streams.

Is there, I ask, can there be, a more interesting study than that of alternating currents?

In all these investigations, in all these experiments, which are so very, very interesting, for many years past—ever since the greatest experimenter who lectured in this hall discovered its principle—we have had a steady companion, an appliance familiar to every one, a plaything once, a thing of momentous importance now—the induction coil. There is no dearer appliance to the electrician. From the ablest among you, I dare say, down to the inexperienced student, to your lecturer, we all have passed many delightful hours in experimenting with the induction coil. We have watched its play, and thought and pondered over the beautiful phenomena which it disclosed to our ravished eyes. So well known is this apparatus, so familiar are these phenomena to every one, that my courage nearly fails me when I think that I have ventured to address so able an audience, that I have ventured to entertain you with that same old subject. Here in reality is the same apparatus, and here are the same phenomena, only the apparatus is operated somewhat differently, the phenomena are presented in a different aspect. Some of the results we find as expected, others surprise us, but

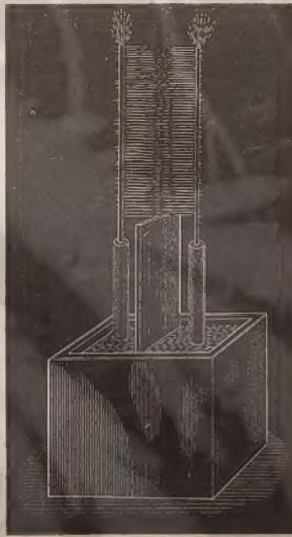


FIG. 1.—DISCHARGE BETWEEN TWO WIRES WITH FREQUENCIES OF A FEW HUNDRED THOUSAND PER SECOND.

all captivate our attention, for in scientific investigation each novel result achieved may be the centre of a new departure, each novel fact learned may lead to important developments.

Usually in operating an induction coil we have set up a vibration of moderate frequency in the primary, either by means of an interrupter or break, or by the use of an alternator. Earlier English investigators, to mention only Spottiswoode and J. E. H. Gordon, have used a rapid break in connection with the coil. Our knowledge and experience of to-day enables us to see clearly why these coils under the conditions of the tests did not disclose any remarkable phenomena, and why able experimenters failed to perceive many of the curious effects which have since been observed.

In the experiments such as performed this evening, we operate the coil either from a specially constructed alternator capable of giving many thousands of reversals of current per second, or, by disruptively discharging a condenser through the primary, we set up a vibration in the secondary circuit of a frequency of many hundred thousand or millions per second, if we so desire; and in using either of these means we enter a field as yet unexplored.

It is impossible to pursue an investigation in any novel line without finally making some interesting observation or learning some useful fact. That this statement is applicable to the subject of this lecture the many curious and unexpected phenomena which we observe afford a convincing proof. By way of illustration, take for instance the most obvious phenomena, those of the discharge of the induction coil.

Here is a coil which is operated by currents vibrating with extreme rapidity, obtained by disruptively discharging a Leyden jar. It would not surprise a student were the lecturer to say that the secondary of this coil consists of a small length of comparatively stout wire; it would not surprise him were the lecturer to state that, in spite of this, the coil is capable of giving any potential which the best insulation of the turns is able to withstand; but although he may be prepared, and even be indifferent as to the anti-

pated result, yet the aspect of the discharge of the coil will surprise and interest him. Every one is familiar with the discharge of an ordinary coil; it need not be reproduced here. But, by way of contrast, here is a form of discharge of a coil, the primary current of which is vibrating several hundred thousand times per second. The discharge of an ordinary coil appears as a simple line or band of light. The discharge of this coil appears in the form of powerful brushes and luminous streams issuing from all points of the two straight wires attached to the terminals of the secondary.

Now compare this phenomenon which you have just witnessed with the discharge of a Holtz or Wimshurst machine—that other interesting appliance so dear to the experimenter. What a difference there is between these phenomena! And yet, had I made the necessary arrangements—which could have been made easily, were it not that they would interfere with other experiments—I could have produced with this coil sparks which, had I the coil hidden from your view and only two knobs exposed, even the keenest observer among you would find it difficult, if not impossible, to distinguish from those of an influence or friction machine. This may be done in many ways—for instance, by operating the induction coil which charges the condenser from an alternating-current machine of very low frequency, and preferably adjusting the discharge circuit so that there are no oscillations set up in it. We then obtain in the secondary circuit, if the knobs are of the required size and properly set, a more or less rapid succession of sparks of great intensity and small quantity, which possess the same brilliancy, and are accompanied by the same sharp crackling sound, as those obtained from a friction or influence machine.

Another way is to pass through two primary circuits, having a common secondary, two currents of a slightly different period, which produce in the secondary circuit sparks occurring at comparatively long intervals. But, even with the means at hand this evening, I may succeed in imitating the spark of a Holtz machine. For this purpose I establish between the terminals of the coil which charges the condenser a long, unsteady arc, which is periodically interrupted by the upward current of air produced by it. To increase the current of air I place on each side of the arc, and close to it, a large plate of mica. The condenser charged from this coil discharges into the primary circuit of a second coil through a small air gap, which is necessary to produce a sudden rush of current through the primary. The scheme of connections in the present experiment is indicated in Fig. 2.

G is an ordinarily constructed alternator, supplying the primary P of an induction coil, the secondary S of which charges the condensers or jars C C. The terminals of the secondary are connected to the inside coatings of the jars, the outer coatings being connected to the ends of the primary p p of a second induction coil. This primary p p has a small air gap a b.

The secondary s of this coil is provided with knobs or spheres K K of the proper size and set at a distance suitable for the experiment.

A long arc is established between the terminals A B of the first induction coil. M M are the mica plates.

Each time the arc is broken between A and B the jars are quickly charged and discharged through the primary p p, producing a snapping spark between the knobs K K. Upon the arc forming between A and B the potential falls, and the jars cannot be charged to such high potential as to break through the air gap a b until the arc is again broken by the draught.

In this manner sudden impulses, at long intervals, are produced in the primary p p, which in the secondary s give a corresponding number of impulses of great intensity. If the secondary knobs or spheres, K K, are of the proper size, the sparks show much resemblance to those of a Holtz machine.

But these two effects, which to the eye appear so very different, are only two of the many discharge phenomena. We only need to change the conditions of the test, and again we make other observations of interest.

When, instead of operating the induction coil as in the two last experiments, we operate it from a high frequency alternator, as in the next experiment, a systematic study of the phenomena is rendered much more easy. In such case, in varying the strength and frequency of the currents through the primary, we may observe five distinct forms of discharge, which I have described in my former paper on the subject* before the American Institute of Electrical Engineers, May 20, 1891.

It would take too much time, and it would lead us too far from the subject presented this evening, to reproduce all these forms, but it seems to me desirable to show you one of them. It is a brush discharge, which is interesting in more than one respect. Viewed from a near position it resembles much a jet of gas escaping under great pressure. We know that the phenomenon is due to the agitation of the molecules near the terminal, and we anticipate that some heat must be developed by the impact of the molecules against the terminal or against each other. Indeed, we find that the brush is hot, and only a little thought leads us to the conclusion that, could we but reach sufficiently high frequencies, we could produce a brush which would give intense light and heat, and which would resemble in every particular an ordinary flame, save, perhaps, that both phenomena might not be due to the same agent—save, perhaps, that chemical affinity might not be electrical in its nature.

As the production of heat and light is here due to the impact of the molecules, or atoms of air, or something else besides, and, as we can augment the energy simply by raising the potential, we might, even with frequencies obtained from a dynamo machine, intensify the action to such a degree as to bring the terminal to melting heat. But with such low frequencies we would have to deal always with something of the nature of an electric current. If I approach a conducting object to the brush, a thin little spark passes, yet, even with the frequencies used this

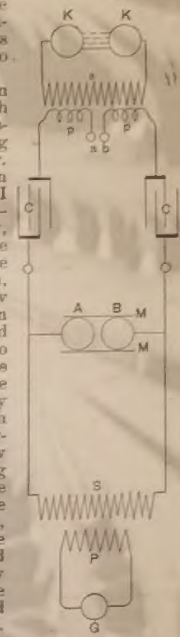


FIG. 2.—IMITATING THE SPARK OF A HOLTZ MACHINE

*See THE ELECTRICAL WORLD, July 11, 1891

evening, the tendency to spark is not very great. So, for instance, if I hold a metallic sphere at some distance above the terminal you may see the whole space between the terminal and sphere illuminated by the streams without the spark passing; and with the much higher frequencies obtainable by the disruptive discharge of a condenser, were it not for the sudden impulses, which are comparatively few in number, sparking would not occur even at very small distances. However, with incomparably higher frequencies, which we may yet find means to produce efficiently, and provided that electric impulses of such high frequencies could be transmitted through a conductor, the electrical characteristics of the brush discharge would completely vanish—no spark would pass, no shock would be felt—yet we would still have to deal with an electric phenomenon, but in the broad, modern interpretation of the word. In my first paper before referred to I have pointed out the curious properties of the brush, and described the best manner of producing it, but I have thought it worth while to endeavor to express myself more clearly in regard to this phenomenon, because of its absorbing interest.

When a coil is operated with currents of very high frequency, beautiful brush effects may be produced, even if the coil be of comparatively small dimensions. The experimenter may vary them in many ways, and, if it were nothing else, they afford a pleasing sight. What adds to their interest is that they may be produced with one single terminal as well as with two—in fact, often better with one than with two.

But of all the discharge phenomena observed, the most pleasing to the eye, and the most instructive, are those observed with a coil which is operated by means of the disruptive discharge of a condenser. The power of the brushes, the abundance of the sparks, when the conditions are patiently adjusted, is often amazing. With even a very small coil, if it be so well insulated as to stand a difference of potential of several thousand volts per turn, the sparks may be so abundant that the whole coil may appear a complete mass of fire.

Curiously enough the sparks, when the terminals of the coil are set at a considerable distance, seem to dart in every possible direction as though the terminals were perfectly independent of each other. As the sparks would soon destroy the insulation it is necessary to prevent them. This is best done by immersing the coil in a good liquid insulator, such as boiled-out oil. Immersion in a liquid may be considered almost an absolute necessity for the continued and successful working of such a coil.

It is of course out of the question, in an experimental lecture, with only a few minutes at disposal for the performance of each experiment, to show these discharge phenomena to advantage, as to produce each phenomenon at its best a very careful adjustment is required. But even if imperfectly produced, as they are likely to be this evening, they are sufficiently striking to interest an intelligent audience.

Before showing some of these curious effects I must, for the sake of completeness, give a short description of the coil and other apparatus used in the experiments with the disruptive discharge this evening.

It is contained in a box *B* (Fig. 3) of thick boards of hard wood, covered on the outside with zinc sheet *Z*, which is carefully soldered all around. It might be advisable, in a strictly scientific investigation, when accuracy is of great importance, to do away with the metal cover, as it might introduce many errors, principally on account of its complex action upon the coil, as a condenser of very small capacity and as an electrostatic and electromagnetic screen. When the coil is used for such experiments as are here contemplated, the employment of the metal cover offers some practical advantages, but these are not of sufficient importance to be dwelt upon.

The coil should be placed symmetrically to the metal

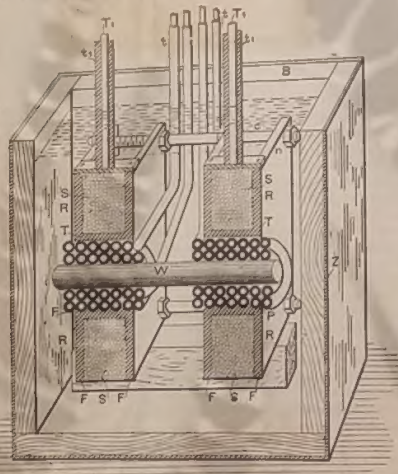


FIG. 3.—DISRUPTIVE DISCHARGE COIL.

cover, and the space between should, of course, not be too small, certainly not less than, say, five centimetres, but much more if possible; especially the two sides of the zinc box, which are at right angles to the axis of the coil, should be sufficiently remote from the latter, as otherwise they might impair its action and be a source of loss.

The coil consists of two spools of hard rubber *R R*, held apart at a distance of 10 centimetres by bolts *c* and nuts *n*, likewise of hard rubber. Each spool comprises a tube *T* of approximately 8 centimetres inside diameter, and 3 millimetres thick, upon which are screwed two flanges *F F*, 24 centimetres square, the space between the flanges being about 3 centimetres. The secondary, *S S*, of the best gutta percha-covered wire, has 26 layers, 10 turns in each, giving for each half a total of 260 turns. The two halves are wound oppositely and connected in series, the connection between both being made over the primary. This disposition, besides being convenient, has the advantage that when the coil is well balanced—that is, when both of its terminals *T, T*, are connected to bodies or devices of equal capacity—there is not much danger of breaking through to the primary, and the insulation between the primary and the secondary need not be thick. In using the

coil it is advisable to attach to both terminals devices of nearly equal capacity, as, when the capacity of the terminals is not equal, sparks will be apt to pass to the primary. To avoid this, the middle point of the secondary may be connected to the primary, but this is not always practicable.

The primary *P P* is wound in two parts, and oppositely, upon a wooden spool *W*, and the four ends are led out of the oil through hard rubber tubes *l l*. The ends of the secondary *T, T*, are also led out of the oil through rubber tubes *t, t* of great thickness. The primary and second-

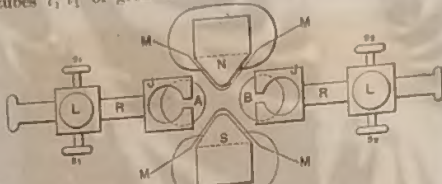


FIG. 4.—ARRANGEMENT OF IMPROVED DISCHARGER AND MAGNET.

ary layers are insulated by cotton cloth, the thickness of the insulation, of course, bearing some proportion to the difference of potential between the turns of the different layers. Each half of the primary has four layers, 24 turns in each, this giving a total of 96 turns. When both the in each, this gives a ratio of conversion in multiple, of about 1:2.7, and with the primaries in multiple, this ratio does not convey even an approximate idea of the ratio of the E. M. Fs. in the primary and secondary circuits. The coil is held in position in the oil on wooden supports, there being about 5 centimetres thickness of oil supports. Where the oil is not specially needed, the space all round, the coil is filled with pieces of wood, and for this purpose principally the wooden box *B* surrounding the whole is used.

The construction here shown is, of course, not the best on general principles, but I believe it is a good and convenient one for the production of effects in which an excessive potential and a very small current are needed.

In connection with the coil I use either the ordinary form of discharger or a modified form. In the former I have introduced two changes which secure some advantages, and which are obvious. If they are mentioned, it is only in the hope that some experimenter may find them of use.

One of the changes is that the adjustable knobs *A* and *B*

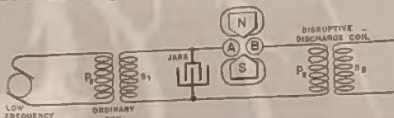


FIG. 5.—ARRANGEMENT WITH LOW-FREQUENCY ALTERNATOR AND IMPROVED DISCHARGER.

(Fig. 4), of the discharger are held in jaws of brass, *J J*, by spring pressure, this allowing of turning them successively into different positions, and so doing away with the tedious process of frequent polishing up.

The other change consists in the employment of a strong electromagnet *N S*, which is placed with its axis at right angles to the line joining the knobs *A* and *B*, and produces a strong magnetic field between them. The pole pieces of the magnet are movable and properly formed so as to protrude between the brass knobs, in order to make the field as intense as possible; but to prevent the discharge from jumping to the magnet the pole pieces are protected by a layer of mica, *M M*, of sufficient thickness. *s, s,* and *s, s,* are screws for fastening the wires. On each side one of the screws is for large and the other for small wires. *L L* are screws for fixing in position the rods *R R*, which support the knobs.

In another arrangement with the magnet I take the discharge between the rounded pole pieces themselves, which in such case are insulated and preferably provided with polished brass caps.

The employment of an intense magnetic field is of advantage principally when the induction coil or transformer which charges the condenser is operated by currents of very low frequency. In such a case the number of the fundamental discharges between the knobs may be so small as to render the currents produced in the secondary unsuitable for many experiments. The intense magnetic field then serves to blow out the arc between the knobs as soon as it is formed, and the fundamental discharges occur in quicker succession.

Instead of the magnet, a draught or blast of air may be employed with some advantage. In this case the arc is preferably established between the knobs *A B*, in Fig. 2 (the knobs *a b* being generally joined, or entirely done away with), as in this disposition the arc is long and unsteady, and is easily affected by the draught.

When a magnet is employed to break the arc, it is better to choose the connection indicated diagrammatically in Fig. 5, as in this case the currents forming the arc are much more powerful, and the magnetic field exercises a greater influence. The use of the magnet permits, however, of the arc being replaced by a vacuum tube, but I have encountered great difficulties in working with an exhausted tube.

The other form of discharger used in these and similar experiments is indicated in Figs. 6 and 7. It consists of a number of brass pieces *c c* (Fig. 6), each of which comprises a spherical middle portion *m* with an extension *e* below—

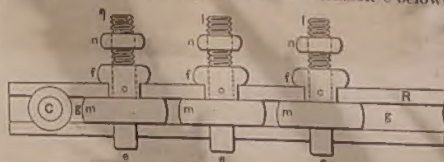


FIG. 6.—DISCHARGER WITH MULTIPLE GAPS.

which is merely used to fasten the piece in a lathe when polishing up the discharging surface—and a column above, which consists of a knurled flange *f* surmounted by a threaded stem *l* carrying a nut *n*, by means of which a wire is fastened to the column. The flange *f* conveniently serves for holding the brass piece when fastening the wire.

and also for turning it in any position when it becomes necessary to present a fresh discharging surface. Two stout strips of hard rubber *R R*, with planed grooves *g g* (Fig. 7) to fit the middle portion of the pieces *c c*, serve to clamp the latter and hold them firmly in position by means of two bolts *C C* (of which only one is shown) passing through the ends of the strips.

In the use of this kind of discharger I have found three principal advantages over the ordinary form. First, the dielectric strength of a given total width of air space is greater when a great many small air gaps are used instead of one, which permits of working with a smaller length of air gap, and that means smaller loss and less deterioration of the metal; secondly by reason of splitting the arc up into smaller arcs, the polished surfaces are made to last much longer; and, thirdly, the apparatus affords some gauge in the experiments. I usually set the pieces by putting between them sheets of uniform thickness at a certain very small distance which is known from the experiments of Sir William Thomson to require a certain electromotive force to be bridged by the spark.

It should, of course, be remembered that the sparking distance is much diminished as the frequency is increased. By taking any number of spaces the experimenter has a rough idea of the electromotive force, and he finds it easier to repeat an experiment, as he has not the trouble of setting the knobs again and again. With this kind of discharger I have been able to maintain an oscillating motion without any spark being visible with the naked eye between the knobs, and they would not show a very appreciable rise in temperature. This form of discharge also lends itself to many arrangements of condensers and circuits which are very convenient and time-saving. I have used it often in a disposition similar to that indicated in Fig. 2, preferably in the currents forming the arc are small.

I may here mention that I have also used dischargers with single or multiple air gaps, in which the discharge surfaces were rotated with great speed. No particular advantage was, however, gained by this method, except in cases where the currents from the condenser were large and the keeping cool of the surfaces was necessary, and in cases when, the discharge not being oscillating of itself, the arc as soon as established was broken by the air current, thus starting the vibration at intervals in rapid succession. I have also used mechanical interrupters in many ways. To avoid the difficulties with frictional contacts, the preferred plan adopted was to establish the arc and rotate through it at great speed a rim of mica provided with many holes and fastened to a steel plate. It is understood, of course, that the employment of a magnet, air current, or other interrupter, produces an effect worth noticing, unless the self-induction, capacity and resistance are so related that there are oscillations set up upon each interruption.

I will now endeavor to show you some of the most noteworthy of these discharge phenomena.

I have stretched across the room two ordinary cotton covered wires, each about 7 metres in length. They are supported on insulating cords at a distance of about 30 centimetres. I attach now to each of the terminals of the coil one of the wires and set the coil in action. Upon turning the lights off in the room you see the wires strongly illuminated by the streams issuing abundantly from their whole surface in spite of the cotton covering, which may even be very thick. When the experiment is performed under good conditions, the light from the wires is sufficiently intense to allow distinguishing the objects in a room. To produce the best result it is, of course, necessary to adjust carefully the capacity of the jars, the arc between the knobs and the length of the wires. My experience is that calculation of the length of the wires leads, in such case, to no result whatever. The experimenter will do best to take the wires at the start very long, and then adjust by cutting off first long pieces, and then smaller and smaller ones as he approaches the right length.

A convenient way is to use an oil condenser of very small capacity, consisting of two small adjustable metal plates, in connection with this and similar experiments. In such case I take wires rather short and set at the beginning the condenser plates at maximum distance. If the streams for the wires increase by approach of the

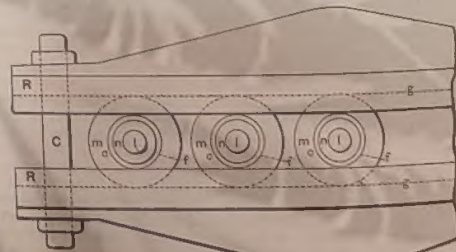


FIG. 7.—DISCHARGER WITH MULTIPLE GAPS.

plates, the length of the wires is about right; if they diminish the wires are too long for that frequency and potential. When a condenser is used in connection with experiments with such a coil, it should be an oil condenser by all means, as in using an air condenser considerable energy might be wasted. The wires leading to the plates in the oil should be very thin, heavily coated with some insulating compound, and provided with a conducting covering—this preferably extending under the surface of the oil. The conducting cover should not be too near the terminals, or ends, of the wire, as a spark would be apt to jump from the wire to it. The conducting coating is used to diminish the air losses, in virtue of its action as an electrostatic screen. As to the size of the vessel containing the oil, and the size of the plates, the experimenter gains at once an idea from a rough trial. The size of the plates in oil is, however, calculable, as the dielectric losses are very small.

In the preceding experiment it is of considerable interest to know what relation the quantity of the light emitted bears to the frequency and potential of the electric effects. My opinion is that the heat as well as light effects produced should be proportionate, under otherwise equal conditions of test, to the product of frequency and square of potential, but the experimental verification of the law, whatever it may be, would be exceedingly difficult. One thing is certain, at any rate, and that is, that in augmenting the potential and frequency we rapidly intensify the streams; and, though it may be very sanguine, it is surely not altogether hopeless to expect that we may succeed in producing a practical illuminant on these lines. We would

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then be simply using burners or flames, in which there would be no chemical process, no consumption of material, but merely a transfer of energy, and which would, in all probability emit more light and less heat than ordinary flames.

The luminous intensity of the streams is, of course, considerably increased when they are focused upon a small surface. This may be shown by the following experiment: I attach to one of the terminals of the coil a wire *w* (Fig. 8), bent in a circle of about 30 centimetres in diameter, and to the other terminal I fasten a small brass sphere *s*, the surface of the wire being preferably equal to the surface of the sphere, and the centre of the latter being in a line at right angles to the plane of the wire circle and passing through its centre. When the discharge is established under proper conditions, a luminous hollow cone is formed, and in the dark one-half of the brass sphere is strongly illuminated, as shown in the cut.

By some artifice or other, it is easy to concentrate the streams upon small surfaces and to produce very strong light effects. Two thin wires may thus be rendered intensely luminous.

In order to intensify the streams the wires should be very thin and short; but as in this case their capacity would be generally too small for the coil—at least, for such a one as the present—it is necessary to augment the capacity to the required value, while, at the same time, the surface of the wires remains very small. This may be done in many ways.

Here, for instance, I have two plates, *R R*, of hard rubber (Fig. 9), upon which I have glued two very thin wires *w w*, so as to form a name. The wires may be bare or covered with the best insulation—it is immaterial for the success of the experiment. Well insulated wires, if anything, are preferable. On the back of each plate, indicated by the shaded portion, is a tinfoil coating *t t*. The plates are placed in line at a sufficient distance to prevent a spark passing from one to the other wire. The two tinfoil coatings I have joined by a conductor *C*, and the two wires I presently connect to the terminals of the coil. It is now easy, by varying the strength and frequency of the currents through the primary, to find a point at which the capacity of the system is best suited to the conditions, and the wires become so strongly luminous that, when the light in the room is turned off the name formed by them appears in brilliant letters.

It is perhaps preferable to perform this experiment with a coil operated from an alternator of high frequency, as then, owing to the harmonic rise and fall, the streams are very uniform, though they are less abundant than when produced with such a coil as the present. This experiment, however, may be performed with low frequencies, but much less satisfactorily.

When two wires, attached to the terminals of the coil,

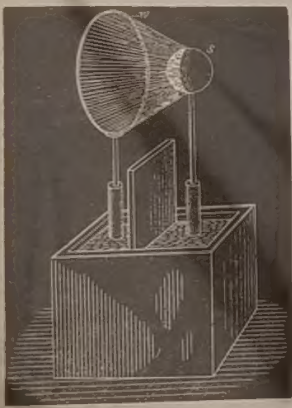


FIG. 8.—EFFECT PRODUCED BY CONCENTRATING STREAMS.

are set at the proper distance, the streams between them may be so intense as to produce a continuous luminous sheet. To show this phenomenon I have here two circles, *C* and *c* (Fig. 10), of rather stout wire, one being about 80 centimetres and the other 30 centimetres in diameter. To each of the terminals of the coil I attach one of the circles. The supporting wires are so bent that the circles may be placed in the same plane, coinciding as nearly as possible. When the light in the room is turned off and the coil set to work, you see the whole space between the wires uniformly filled with streams, forming a luminous disc, which could be seen from a considerable distance, such is the intensity of the streams. The outer circle could have been much larger than the present one; in fact, with this coil I have used much larger circles, and I have been able to produce a strongly luminous sheet, covering an area of more than one square metre, which is a remarkable effect with this very small coil. To avoid uncertainty, the circle has been taken smaller, and the area is now about 0.43 square metre.

The frequency of the vibration, and the quickness of succession of the sparks between the knobs, affect to a marked degree the appearance of the streams. When the frequency is very low, the air gives way in more or less the same manner, as by a steady difference of potential, and the streams consist of distinct threads, generally mingled with thin sparks, which probably correspond to the successive discharges occurring between the knobs. But when the frequency is extremely high, and the arc of the discharge produces a very loud but smooth sound—showing both that oscillation takes place and that the sparks succeed each other with great rapidity—then the luminous streams formed are perfectly uniform. To reach this result very small coils and jars of small capacity should be used. I take two tubes of thick Bohemian glass, about 5 centimetres in diameter and 20 centimetres long. In each of the tubes I slip a primary of very thick copper wire. On the top of each tube I wind a secondary of much thinner gutta-percha covered wire. The two secondaries I connect in series, the primaries preferably in multiple arc. The tubes are then placed in a large glass vessel, at a distance of 10 to 15 centimetres from each other, on insulating supports, and the vessel is filled with boiled-out oil, the oil reaching about an inch above the tubes. The free ends of the secondary are lifted out of the oil and placed parallel to each other at a distance of about 10 centimetres. The ends which are scraped should be dipped in

the oil. Two four-pint jars joined in series may be used to discharge through the primary. When the necessary adjustments in the length and distance of the wires above the oil and in the arc of discharge are made, a luminous sheet is produced between the wires which is perfectly smooth and textureless, like the ordinary discharge through a moderately exhausted tube.

I have purposely dwelt upon this apparently insignificant experiment. In trials of this kind the experimenter arrives at the startling conclusion that, to pass ordinary luminous discharges through gases, no particular degree of exhaustion is needed, but that the gas may be at ordinary or even greater pressure. To accomplish this, a very high fre-

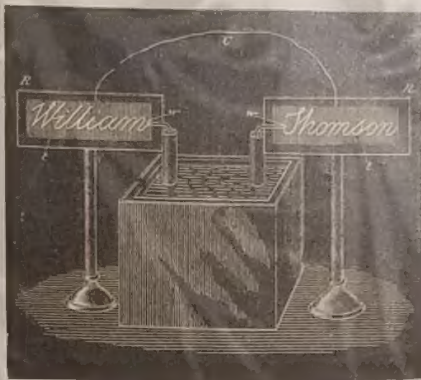


FIG. 9.—WIRES RENDERED INTENSELY LUMINOUS.

quency is essential; a high potential is likewise required, but this is a merely incidental necessity. These experiments teach us that, in endeavoring to discover novel methods of producing light by the agitation of atoms, or molecules, of a gas, we need not limit our research to the vacuum tube, but may look forward quite seriously to the possibility of obtaining the light effects without the use of any vessel whatever, with air at ordinary pressure.

Such discharges of very high frequency, which render luminous the air at ordinary pressures, we have probably often occasion to witness in Nature. I have no doubt that if, as many believe, the aurora borealis is produced by sudden cosmic disturbances, such as eruptions at the sun's surface, which set the electrostatic charge of the earth in an extremely rapid vibration, the red glow observed is not confined to the upper rarefied strata of the air, but the discharge traverses, by reason of its very high frequency, also the dense atmosphere in the form of a glow, such as we ordinarily produce in a slightly exhausted tube. If the frequency were very low, or even more so, if the charge were not at all vibrating, the dense air would break down as in a lightning discharge. Indications of such breaking down of the lower dense strata of the air have been repeatedly observed at the occurrence of this marvelous phenomenon; but if it does occur, it can only be attributed to the fundamental disturbances, which are few in number, for the vibration produced by them would be far too rapid to allow a disruptive break. It is the original and irregular impulses which affect the instruments; the superimposed vibrations probably pass unnoticed.

When an ordinary low frequency discharge is passed through moderately rarefied air, the air assumes a purplish hue. If by some means or other we increase the intensity of the molecular, or atomic, vibration, the gas changes to a white color. A similar change occurs at ordinary pressures with electric impulses of very high frequency. If the molecules of the air around a wire are moderately agitated, the brush formed is reddish or violet; if the vibration is rendered sufficiently intense, the streams become white. We may accomplish this in various ways. In the experiment before shown with the two wires across the room, I have endeavored to secure the result by pushing to a high value both the frequency and potential; in the experiment with the thin wires glued on the rubber plate I have concentrated the action upon a very small surface—in other words, I have worked with a great electric density.

A most curious form of discharge is observed with such a coil when the frequency and potential are pushed to the extreme limit. To perform the experiment, every part of the coil should be heavily insulated, and only two small spheres—or, better still, two sharp-edged metal discs (*d d*, Fig. 11) of no more than a few centimetres in diameter—



FIG. 11.—PHANTOM STREAMS.

should be exposed to the air. The coil here used is immersed in oil, and the ends of the secondary reaching out of the oil are covered with an air-tight cover of hard rubber of great thickness. All cracks, if there are any, should be carefully stopped up, so that the brush discharge cannot form anywhere except on the small spheres or plates which are exposed to the air. In this case, since there are no large plates or other bodies of capacity attached to the terminals, the coil is capable of an extremely rapid vibration. The potential may be raised by increasing,

as far as the experimenter judges proper, the rate of change of the primary current. With a coil not widely differing from the present, it is best to connect the two primaries in multiple arc; but if the secondary should have a much greater number of turns the primaries should preferably be used in series, as otherwise the vibration might be too fast for the secondary. It occurs under these conditions that misty white streams break forth from the edges of the discs and spread out phantom-like into space. With this coil, when fairly well produced, they are about 25 to 50 centimetres long. When the hand is held against them no sensation is produced, and a spark, causing a shock, jumps from the terminal only upon the hand being brought much nearer. If the oscillation of the primary current is rendered intermittent by some means or other, there is a corresponding throbbing of the streams, and now the hand or other conducting object may be brought in still greater proximity to the terminal without a spark being caused to jump.

Among the many beautiful phenomena which may be produced with such a coil I have here selected only those which appear to possess some features of novelty, and lead us to some conclusions of interest. One will not find it at all difficult to produce in the laboratory, by means of it, many other phenomena which appeal to the eye even more than these here shown, but present no particular feature of novelty.

Early experimenters describe the display of sparks produced by an ordinary large induction coil upon an insulating plate separating the terminals. Quite recently Siemens performed some experiments in which fine effects were obtained, which were seen by many with interest. No doubt large coils, even if operated with currents of low frequencies, are capable of producing beautiful effects. But the largest coil ever made could not, by far, equal the magnificent display of streams and sparks obtained from such a disruptive discharge coil when properly adjusted. To give an idea, a coil such as the present one will cover easily a plate of 1 metre in diameter completely with the streams. The best way to perform such experiments is to take a very thin rubber or a glass plate and glue on one side of it a narrow ring of tinfoil of very large diameter, and on the other a circular washer, the centre of the latter coinciding with that of the ring, and the surfaces of both being preferably equal, so as to keep the coil well balanced. The washer and ring should be connected to the terminals by heavily insulated thin wires. It is easy in observing the effect of the capacity to produce a sheet of uniform streams, or a fine network of thin silvery threads, or a mass of loud brilliant sparks, which completely cover the plate.

Since I have advanced the idea of the conversion by

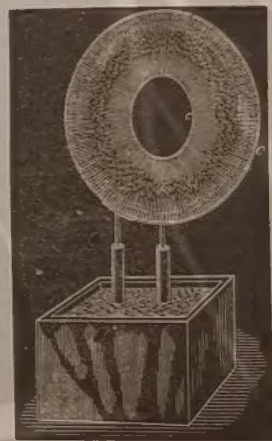


FIG. 10.—LUMINOUS DISCS.

means of the disruptive discharge, in my paper before the American Institute of Electrical Engineers at the beginning of the past year, the interest excited in it has been considerable. It affords us a means for producing any potentials by the aid of inexpensive coils operated from ordinary systems of distribution, and—what is perhaps more appreciated—it enables us to convert currents of any frequency into currents of any other lower or higher frequency. But its chief value will perhaps be found in the help which it will afford us in the investigations of the phenomena of phosphorescence, which a disruptive discharge coil is capable of exciting in innumerable cases where ordinary coils, even the largest, would utterly fail. Considering its probable uses for many practical purposes, and its possible introduction into laboratories for scientific research, a few additional remarks as to the construction of such a coil will perhaps not be found superfluous.

It is, of course, absolutely necessary to employ in such a coil wires provided with the best insulation.

Good coils may be produced by employing wires covered with several layers of cotton, boiling the coil a long time in pure wax, and cooling under moderate pressure. The advantage of such a coil is that it can be easily handled, but it cannot probably give as satisfactory results as a coil immersed in pure oil. Besides, it seems that the presence of a large body of wax affects the coil disadvantageously, whereas this does not seem to be the case with oil. Perhaps it is because the dielectric losses in the liquid are smaller.

I have tried at first silk and cotton covered wires with oil immersion, but I have been gradually led to use gutta-percha covered wires, which proved most satisfactory. Gutta-percha insulation adds, of course, to the capacity of the coil, and this, especially if the coil be large, is a great disadvantage when extreme frequencies are desired; but, on the other hand, gutta-percha will withstand much more than an equal thickness of oil, and this advantage should be secured at any price. Once the coil has been immersed, it should never be taken out of the oil for more than a few hours, else the gutta-percha will crack up and the coil will not be worth half as much as before. Gutta-percha is probably slowly attacked by the oil, but after an immersion of eight to nine months I have found no ill effects.

I have obtained in commerce two kinds of gutta-percha wire: in one the insulation sticks tightly to the metal, in the other it does not. Unless a special method is followed to expel all air, it is much safer to use the first kind. I

wind the coil within an oil tank so that all interstices are filled up with the oil. Between the layers I use cloth boiled out thoroughly in oil, calculating the thickness according to the difference of potential between the turns. There seems not to be a very great difference whatever kind of oil is used; I use paraffine or linseed oil.

To exclude more perfectly the air, an excellent way to proceed, and easily practicable with small coils, is the following: Construct a box of hard wood of very thick boards which have been for a long time boiled in oil. The boards should be so joined as to safely withstand the external air pressure. The coil being placed and fastened in position within the box, the latter is closed with a strong lid, and covered with closely fitting metal sheets, the joints of which are soldered very carefully. On the top two small holes are drilled, passing through the metal sheet and the wood, and in these holes two small glass tubes are inserted and the joints made air-tight. One of the tubes is connected to a vacuum pump, and the other with a vessel containing a sufficient quantity of boiled-out oil. The latter tube has a very small hole at the bottom, and is provided with a stopcock. When a fairly good vacuum has been obtained, the stopcock is opened and the oil slowly fed in. Proceeding in this manner, it is impossible that any big bubbles, which are the principal danger, should remain between the turns. The air is most completely excluded, probably better than by boiling out, which, however, when gutta-percha coated wires are used, is not practicable.

For the primaries I use ordinary line wire with a thick cotton coating. Strands of very thin insulated wires

The exclusion of gaseous matter from any apparatus in which the dielectric is subjected to more or less rapidly changing electric forces is, however, not only desirable in order to avoid a possible injury of the apparatus, but also on account of economy. In a condenser, for instance, as long as only a solid or only a liquid dielectric is used, the loss is small; but if a gas under ordinary or small pressure be present the loss may be very great.

Whatever the nature of the force acting in the dielectric may be, it seems that in a solid or liquid the molecular displacement produced by the force is small; hence the force be very great; but in a gas the displacement, and therefore this product, is considerable; the molecules are free to move, they reach high speeds, and the energy of their impact is lost in heat or otherwise. If the gas be strongly compressed, the displacement due to the force is made smaller, and the losses are reduced.

In most of the succeeding experiments I prefer, chiefly on account of the regular and positive action, to employ the alternator before referred to. This is one of the several machines constructed by me for the purposes of these investigations. It has 384 pole projections, and is capable of giving currents of a frequency of about 10,000 per second. This machine has been illustrated and briefly described in my first paper before the American Institute of Electrical Engineers, May 20, 1891, to which I have already referred. A more detailed description, sufficient to enable any engineer to build a similar machine, will be found in several electrical journals of that period.

The induction coils operated from the machine are rather small, containing from 5,000 to 15,000 turns in the second, contained in boiled-out linseed oil, contrary. They are immersed in wooden boxes covered with zinc sheet.

I have found it advantageous to reverse the usual position of the wires, and to wind, in these coils, the primaries on the top; this allowing the use of a much bigger primary, which, of course, reduces the danger of overheating and increases the output of the coil. I make the primary on each side at least one centimetre shorter than the secondary, to prevent the breaking through on the ends, which would surely occur unless the insulation on the top of the secondary be very thick, and this, of course, would be disadvantageous.

When the primary is made movable, which is necessary in some experiments, and many times convenient for the purposes of adjustment, I cover the secondary with wax, and turn it off in a lathe to a diameter slightly smaller than the inside of the primary coil. The latter I provide with a handle reaching out of the oil, which serves to shift it in any position along the secondary.

I will now venture to make, in regard to the general manipulation of induction coils, a few observations bearing upon points which have not been fully appreciated in earlier experiments with such coils, and are even now often overlooked.

The secondary of the coil possesses usually such a high self-induction that the current through the wire is inappreciable, and may be so even when the terminals are joined by a conductor of small resistance. If capacity is added to the terminals, the self-induction is counteracted, and a stronger current is made to flow through the secondary, though its terminals are insulated from each other. To one entirely unacquainted with the properties of alternating currents nothing will look more puzzling. This feature was illustrated in the experiment performed at the beginning with the top plates of wire gauze attached to the terminals and the rubber plate. When the plates of wire gauze were close together, and a small arc passed between them, the arc prevented a strong current from passing through the secondary, because it did away with the capacity on the terminals; when the rubber plate was inserted between the terminals, the capacity of the condenser formed counteracted the self-induction of the secondary, a stronger current passed now, the coil performed more work, and the discharge was by far more powerful.

The first thing, then, in operating the induction coil is to combine capacity with the secondary to overcome the self-induction. If the frequencies and potentials are very high gaseous matter should be carefully kept away from the charged surfaces. If Leyden jars are used, they should be immersed in oil, as otherwise considerable dissipation may occur if the jars are greatly strained. When high

a bulb having no leading-in wire should be used. I have found it best to use bulbs constructed as indicated in Figs. 12 and 13.

In Fig. 12 the bulb comprises an incandescent lamp globe *L*, in the neck of which is sealed a bimetallic tube *b*, the end of which is blown out to form a small sphere *s*. This sphere should be sealed as closely as possible in the centre of the large globe. Before sealing, a thin tube *t*, of aluminium sheet, may be slipped in the barometer tube, but it is not important to employ it.

The small hollow sphere *s* is filled with some conducting powder, and a wire *w* is cemented in the neck for the purpose of connecting the conducting powder with the generator.

The construction shown in Fig. 13 was chosen in order to remove from the brush any conducting body which might possibly affect it. The bulb consists in this case of a lamp globe *L*, which has a neck *n*, provided with a tube *b* and small sphere *s*, sealed to it, so that two entirely independent compartments are formed, as indicated in the drawing. When the bulb is in use, the neck *n* is provided with a tin-foil coating, which is connected to the generator and acts inductively upon the moderately rarefied and highly conducting gas enclosed in the neck. From there the current passes through the tube *b* into the small sphere *s*, to act by induction upon the gas contained in the globe *L*.

It is of advantage to make the tube *t* very thick, the hole through it very small, and to blow the sphere *s* very thin. It is of the greatest importance that the sphere *s* be placed in the centre of the globe *L*.

Figs. 14, 15 and 16 indicate different forms, or stages, of

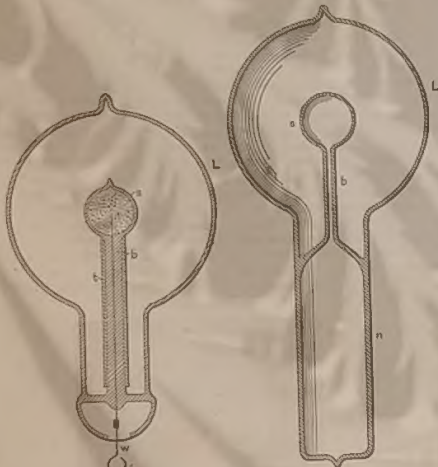


FIG. 12. FIG. 13.
BULBS FOR PRODUCING ROTATING BRUSH.

properly interlaced would, of course, be the best to employ for the primaries, but they are not to be had.

In an experimental coil the size of the wires is not of great importance. In the coil here used the primary is No. 12 and the secondary No. 24 Brown & Sharpe gauge wire; but the sections may be varied considerably. It would only imply different adjustments; the results aimed at would not be materially affected.

I have dwelt at some length upon the various forms of brush discharge because, in studying them, we not only observe phenomena which please our eye, but also afford us food for thought, and lead us to conclusions of practical importance. In the use of alternating currents of very high tension, too much precaution cannot be taken to prevent the brush discharge. In a main conveying such currents, the in an induction coil or transformer, or in a condenser, the brush discharge is a source of great danger to the insulation. In a condenser especially the gaseous matter must be most carefully expelled, for in it the charged surfaces are near each other, and if the potentials are high, just as sure as a weight will fall if let go, so the insulation will give way if a single gaseous bubble of some size be present, whereas, if all gaseous matter were carefully excluded, the condenser would safely withstand a much higher difference of potential. A main conveying alternating currents of very high tension may be injured merely by a blowhole or small crack in the insulation, the more so as a blowhole is apt to contain gas at low pressure; and as it appears almost impossible to completely obviate such little imperfections, I am led to believe that in our future distribution of electrical energy by currents of very high tension liquid insulation will be used. The cost is a great drawback, but if we employ an oil as an insulator the distribution of electrical energy with something like 100,000 volts, and even more, become, at least with higher frequencies, so easy that they could be hardly called engineering feats. With oil insulation and alternate current motors transmissions of power can be effected with safety and upon an industrial basis at distances of as much as a thousand miles.

A peculiar property of oils, and liquid insulation in general, when subjected to rapidly changing electric stresses, is to disperse any gaseous bubbles which may be present, and diffuse them through its mass, generally long before any injurious break can occur. This feature may be easily observed with an ordinary induction coil by taking the primary out, plugging up the end of the tube upon which the secondary is wound, and filling it with some fairly transparent insulator, such as paraffine oil. A primary of a diameter something like six millimetres smaller than the inside of the tube may be inserted in the oil. When the coil is set to work one may see, looking from the top through the oil, many luminous points—air bubbles which are caught by inserting the primary, and which are rendered luminous in consequence of the violent bombardment. The occluded air, by its impact against the oil, heats it; the oil begins to circulate, carrying some of the air along with it, until the bubbles are dispersed and the luminous points disappear. In this manner, unless large bubbles are occluded in such way that circulation is rendered impossible, a damaging break is averted, the only effect being a moderate warming up of the oil. If, instead of the liquid, a solid insulation, no matter how thick, were used, a breaking through and injury of the apparatus would be inevitable.

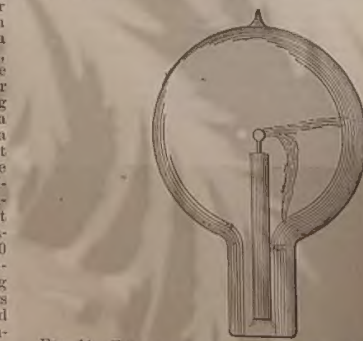


FIG. 14.—FORMS AND PHASES OF THE ROTATING BRUSH.

frequencies are used, it is of equal importance to combine a condenser with the primary. One may use a condenser connected to the ends of the primary or to the terminals of the alternator, but the latter is not to be recommended, as the machine might be injured. The best way is undoubtedly to use the condenser in series with the primary and with the alternator, and to adjust its capacity so as to annul the self-induction of both the latter. The condenser should be adjustable by very small steps, and for a finer adjustment a small oil condenser with movable plates may be used conveniently.

I think it best at this juncture to bring before you a phenomenon, observed by me some time ago, which to the purely scientific investigator may perhaps appear more interesting than any of the results which I have the privilege to present to you this evening.

It may be quite properly ranked among the brush phenomena—in fact, it is a brush, formed at, or near, a single terminal in high vacuum.

In bulbs provided with a conducting terminal, though it be of aluminium, the brush has but an ephemeral existence, and cannot, unfortunately, be indefinitely preserved in its most sensitive state, even in a bulb devoid of any conducting electrode. In studying the phenomenon, by all means

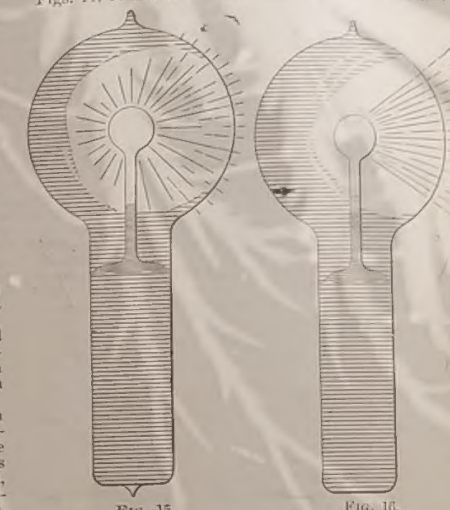


FIG. 15. FIG. 16.
FORMS AND PHASES OF THE ROTATING BRUSH.

the brush. Fig. 14 shows the brush as it first appears in a bulb provided with a conducting terminal; but, as in such a bulb it very soon disappears—often after a few minutes—I will confine myself to the description of the phenomenon as seen in a bulb without conducting electrode. It is observed under the following conditions:

When the globe *L* (Figs. 12 and 13) is exhausted to a very high degree, generally the bulb is not excited upon connecting the wire *w* (Fig. 12) or the tin-foil coating of the bulb (Fig. 13) to the terminal of the induction coil. To excite it, it is usually sufficient to grasp the globe *L* with the hand. An intense phosphorescence then spreads at first over the globe, but soon gives place to a white, misty light. Shortly afterward one may notice that the luminosity is unevenly distributed in the globe, and after passing the current for some time the bulb appears as in Fig. 15. From this stage the phenomenon will gradually pass to that indicated in Fig. 16, after some minutes, hours, days or weeks, according as the bulb is worked. Warming the bulb or increasing the potential hastens the transit.

When the brush assumes the form indicated in Fig. 16, it may be brought to a state of extreme sensitiveness to electrostatic and magnetic influence. The bulb hanging straight down from a wire, and all objects being remote from it, the approach of the observer at a few paces from the bulb will cause the brush to fly to the opposite side, and if he walks around the bulb it will always keep on the opposite side. It may begin to spin around the terminal long before it reaches that sensitive stage. When it begins to turn around principally, but also before, it is affected by a magnet, and at a certain stage it is susceptible to magnetic influence to an astonishing degree. A small permanent magnet, with its poles at a distance of no more than two centimetres, will affect it visibly at a distance according to how it is held relatively to the brush. I think I have observed that at the stage when it is most sensitive to magnetic, it is not most sensitive to electrostatic influence. My explanation is, that the electrostatic attraction between the brush and the glass of the bulb, which retards the rotation, grows much quicker than the magnetic influence when the intensity of the stream is increased.

When the bulb hangs with the globe *L* down, the rotation is always clockwise. In the southern hemisphere it would occur in the opposite direction and on the equator the brush should not turn at all. The rotation may be reversed by a magnet kept at some distance. The brush rotates best, seemingly, when it is at right angles to the lines of force of the earth. It very likely rotates, when at its maximum speed, in synchronism with the alternations, say 10,000 times a second. The rotation can be slowed down or accelerated by the approach or receding of the observer, or any conducting body, but it cannot be reversed by putting the bulb in any position. When it is in the state of the highest sensitiveness and the potential or frequency be varied the sensitiveness is rapidly diminished. Changing either of these but little will generally stop the rotation. The sensitiveness is likewise affected by the variations of temperature. To attain great sensitiveness it is necessary to have the small sphere *s* in the centre of the globe *L*, as otherwise the electrostatic action of the glass of the globe will tend to stop the rotation. The sphere *s* should be small and of uniform thickness; any dissymmetry of course has the effect to diminish the sensitiveness.

The fact that the brush rotates in a definite direction in

a permanent magnetic field seems to show that in alternating currents of very high frequency the positive and negative impulses are not equal, but that one always preponderates over the other.

Of course, this rotation in one direction may be due to the action of two elements of the same current upon each other, or to the action of the field produced by one of the elements upon the other, as in a series motor, without necessarily one impulse being stronger than the other. The fact that the brush turns, as far as I could observe, in any position, would speak for this view. In such case it would turn at any point of the earth's surface. But, on the other hand, it is then hard to explain why a permanent magnet should reverse the rotation, and one must assume the preponderance of impulses of one kind.

As to the causes of the formation of the brush or stream, I think it is due to the electrostatic action of the globe and the dissymmetry of the parts. If the small bulb *x* and the globe *L* were perfect concentric spheres, and the glass throughout of the same thickness and quality, I think the brush would not form, as the tendency to pass would be equal on all sides. That the formation of the stream is due to an irregularity is apparent from the fact that it has the tendency to remain in one position, and rotation occurs most generally only when it is brought out of this position by electrostatic or magnetic influence. When in an extremely sensitive state it rests in one position, most curious experiments may be performed with it. For instance, the experimenter may, by selecting a proper position, approach the hand at a certain considerable distance to the bulb, and he may cause the brush to pass off by merely stiffening the muscles of the arm. When it begins to rotate slowly, and the hands are held at a proper distance, it is impossible to make even the slightest motion without producing a visible effect upon the brush. A metal plate connected to the other terminal of the coil affects it at a great distance, slowing down the rotation often to one turn a second.

I am firmly convinced that such a brush, when we learn how to produce it properly, will prove a valuable aid in the investigation of the nature of the forces acting in an electrostatic or magnetic field. If there is any motion which is measurable going on in the space, such a brush ought to reveal it. It is, so to speak, a beam of light, frictionless, devoid of inertia.

I think that it may find practical applications in telegraphy. With such a brush it would be possible to send dispatches across the Atlantic, for instance, with any speed, since its sensitiveness may be so great that the slightest changes will affect it. If it were possible to make the stream more intense and very narrow, its deflections could be easily photographed.

I have been interested to find whether there is a rotation of the stream itself, or whether there is simply a stress traveling around in the bulb. For this purpose I mounted a light mica fan so that its vanes were in the path of the brush. If the stream itself was rotating the fan would be spun around. I could produce no distinct rotation of the fan, although I tried the experiment repeatedly; but as the fan exerted a noticeable influence on the stream, and the apparent rotation of the latter was, in this case, never quite satisfactory, the experiment did not appear to be conclusive.

I have been unable to produce the phenomenon with the disruptive discharge coil, although every other of these phenomena can be well produced by it—many, in fact, much better than with coils operated from an alternator.

It may be possible to produce the brush by impulses of one direction, or even by a steady potential, in which case it would be still more sensitive to magnetic influence.

In operating an induction coil with rapidly alternating currents, we realize with astonishment, for the first time, the great importance of the relation of capacity, self-induction and frequency as regards the general result. The effects of capacity are the most striking, for in these experiments, since the self-induction and frequency both are high, the critical capacity is very small, and need be but slightly varied to produce a very considerable change. The experimenter may bring his body in contact with the terminals of the secondary of the coil, or attach to one or both terminals insulated bodies of very small bulk, such as bulbs, and he may produce a considerable rise or fall of potential, and greatly affect the flow of the current through the primary. In the experiment before shown, in which a brush appears at a wire attached to one terminal, and the wire is vibrated when the experimenter brings his insulated body in contact with the other terminal of the coil, the sudden rise of potential was made evident.

I may show you the behavior of the coil in another manner which possesses a feature of some interest. I have here a little light fan of aluminium sheet, fastened to a needle and arranged to rotate freely in a metal piece screwed to one of the terminals of the coil. When the coil is set to work, the molecules of the air are rhythmically attracted and repelled. As the force with which they are repelled is greater than that with which they are attracted, it results that there is a repulsion exerted on the surfaces of the fan. If the fan were made simply of a metal sheet, and would produce no effect. But if one of the opposing surfaces is screened, or if, generally speaking, the bombardment on this side is weakened in some way or other, there remains the repulsion exerted upon the other, and the fan is set in rotation. The screening is best effected by fastening upon one of the opposing sides of the fan insulated conducting coatings, or, if the fan is made in the shape of an ordinary propeller screw, by fastening on one side, and close to it, an insulated metal plate. The static screen may, however, be omitted, and simply a thickness of insulating material fastened to one of the sides of the fan.

To show the behavior of the coil, the fan may be placed upon the terminal and it will readily rotate when the coil is operated by currents of very high frequency. With a steady potential, of course, and even with alternating currents of very low frequency, it would not turn, because of the very slow exchange of air and, consequently, smaller bombardment; but in the latter case it might turn if the potential were excessive. With a pin wheel, quite the opposite rule holds good; it rotates best with a steady potential, and the effort is the smaller the higher the frequency. Now, it is very easy to adjust the conditions so that the potential is normally not sufficient to turn the fan, but that by connecting the other terminal of the coil with an insulated body it rises to a much greater value, so as to rotate the fan, and it is likewise possible to stop the rotation by connecting to the terminal a body of different size, thereby diminishing the potential.

Instead of using the fan in this experiment, we may use the "electric" radiometer with similar effect. But in this case it will be found that the vanes will rotate only at high exhaustion or at ordinary pressures; they will not rotate at moderate pressures, when the air is highly conducting.

This curious observation was made conjointly by Professor Crookes and myself. I attribute the result to the high conductivity of the air, the molecules of which then do not act as independent carriers of electric charges, but act all together as a single conducting body. In such case, of course, if there is any repulsion at all of the molecules from the vanes, it must be very small. It is possible, however, that the result is in part due to the fact that the greater part of the discharge passes from the leading-in wire through the highly conducting gas, instead of passing off from the conducting vanes.

In trying the preceding experiment with the electric radiometer the potential should not exceed a certain limit, as then the electrostatic attraction between the vanes and the glass of the bulb may be so great as to stop the rotation.

A most curious feature of alternate currents of high frequencies and potentials is that they enable us to perform many experiments by the use of one wire only. In many respects this feature is of great interest.

In a type of alternate current motor invented by me some years ago I produced rotation by inducing, by means of a single alternating current passed through a motor circuit, in the mass or other circuits of the motor, secondary currents, which, jointly with the primary or inducing current, created a moving field of force. A simple but crude form of such a motor is obtained by winding upon an iron core a primary, and close to it a secondary coil, joining the ends of the latter and placing a freely movable metal disc within the influence of the field produced by both. The iron core is employed for obvious reasons, but it is not essential to the operation. To improve the motor, the iron core is made to encircle the armature. Again to improve, the secondary coil is made to overlap partly the primary, so that it cannot free itself from a strong inductive action of the latter, repel its lines as it may. Once more to improve, the proper difference of phase is obtained between the primary and secondary currents by a condenser, self-induction, resistance or equivalent windings.

I had discovered, however, that rotation is produced by means of a single coil and core; my explanation of the phenomenon, and leading thought in trying the experiment, being that there must be a true time lag in the magnetization of the core. I remember the pleasure I had when, in the writings of Professor Ayrton, which came later to my hand, I found the idea of the time lag advocated. Whether there is a true time lag, or whether the retardation is due to eddy currents circulating in minute paths, must remain an open question, but the fact is that a coil wound upon an iron core and traversed by an alternating

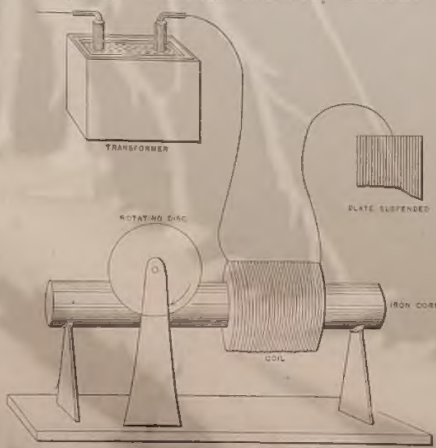


FIG. 17.—SINGLE WIRE AND "NO-WIRE" MOTOR.

current creates a moving field of force, capable of setting an armature in rotation. It is of some interest, in conjunction with the historical Arago experiment, to mention that in lag or phase motors I have produced rotation in the opposite direction to the moving field, which means that in that experiment the magnet may not rotate, or may even rotate in the opposite direction to the moving disc. Here, then, is a motor (diagrammatically illustrated in Fig. 17), comprising a coil and iron core, and a freely movable copper disc in proximity to the latter.

To demonstrate a novel and interesting feature, I have, for a reason which I will explain, selected this type of motor. When the ends of the coil are connected to the terminals of an alternator the disc is set in rotation. But it is not this experiment, now well known, which I desire to perform. What I wish to show you is that this motor rotates with one single connection between it and the generator; that is to say, one terminal of the motor is connected to one terminal of the generator—in this case the secondary of the best-tension induction coil—the other terminals of motor and generator being insulated in space. To produce rotation it is generally (but not absolutely) necessary to connect the free end of the motor coil to an insulated body of some size. The experimenter's body is more than sufficient. If he touches the free terminal with an object held in the hand, a current passes through the coil and the copper disc is set in rotation. If an exhausted tube is put in series with the coil, the tube lights brilliantly, showing the passage of a strong current. Instead of the experimenter's body, a small metal sheet suspended on a cord may be used with the same result. In this case the plate acts as a condenser in series with the coil. It counteracts the self-induction of the latter and allows a strong current to pass. In such a combination, the greater the self-induction of the coil the smaller need be the plate, and this means that a lower frequency, or eventually a lower potential, is required to operate the motor. A single coil wound upon a core has a high self-induction; for this reason principally, this type of motor was chosen to perform the experiment. Were a secondary closed coil wound upon the core, it would tend to diminish the self-induction, and then it would be necessary to employ a much higher frequency and potential. Neither would be advisable, for a higher potential would endanger the insulation of the small primary coil, and a higher frequency would result in a materially diminished torque.

It should be remarked that when such a motor with a closed secondary is used, it is not at all easy to obtain rotation with excessive frequencies, as the secondary cuts off almost completely the lines of the primary—and this, of

course, the more, the higher the frequency—and allows the passage of but a minute current. In such a case, unless the secondary is closed through a condenser, it is almost essential, in order to produce rotation, to make the primary and secondary coils overlap each other more or less.

But there is an additional feature of interest about this motor, namely, it is, not necessary to have even a single connection between the motor and generator, except, perhaps, through the ground; for not only is an insulated plate capable of giving off energy into space, but it is likewise capable of deriving it from an alternating electrostatic field, though in the latter case the available energy is much smaller. In this instance one of the motor terminals is connected to the insulated plate or body located within the alternating electrostatic field, and the other terminal preferably to the ground.

It is quite possible, however, that such "no-wire" motors, as they might be called, could be operated by conduction through the rarefied air at considerable distances. Alternate currents, especially of high frequencies, pass with astonishing freedom through even slightly rarefied gases. The upper strata of the air are rarefied, to reach a number of miles out into space requires the overcoming of difficulties of a merely mechanical nature. There is no doubt that with the enormous potentials obtainable by the use of high frequencies and oil insulation luminous discharges might be passed through many miles of rarefied air, and, that, by thus directing the energy of many hundreds or thousands of horse-power, motors or lamps might be operated at considerable distances from stationary sources. But such schemes are mentioned merely as possibilities. We shall have no need to transmit power at all. Ere many generations pass, our machinery will be driven by a power obtainable at any point of the universe. This idea is not novel. Men have been led to it long ago by instinct or reason. It has been expressed in many ways, and in many places, in the history of old and new. We find it in the delightful myth of Antheus, who derives power from the earth; we find it among the subtle speculations of one of your splendid mathematicians, and in many hints and statements of thinkers of the present time. Throughout space there is energy. Is this energy static or kinetic? If static our hopes are in vain; if kinetic—and this we know it is, for certain—then it is a mere question of time when men will succeed in attaching their machinery to the very wheelwork of nature. Of all, living or dead, Crookes came nearest to doing it. His radiometer will turn in the light of day and in the darkness of the night; it will turn everywhere where there is heat, and heat is everywhere. But, unfortunately, this beautiful little machine, while it goes down to posterity as the most interesting, must likewise be put on record as the most inefficient machine ever invented!

The preceding experiment is only one of many equally interesting experiments which may be performed by the use of only one wire with alternate currents of high potential and frequency. We may connect an insulated line to a source of such currents, we may pass an inappreciable current over the line, and on any point of the same we are able to obtain a heavy current, capable of fusing a thick copper wire. Or we may, by the help of some artifice, decompose a solution in any electrolytic cell by connecting only one pole of the cell to the line or source of energy. Or we may, by attaching to the line, or only bringing into its vicinity, light up an incandescent lamp, an exhausted tube, or a phosphorescent bulb.

However impracticable this plan of working may appear in many cases, it certainly seems practicable, and even recommendable, in the production of light. A perfected lamp would require but little energy, and if wires were used at all we ought to be able to supply that energy without a return wire.

It is now a fact that a body may be rendered incandescent or phosphorescent by bringing it either in single contact or merely in the vicinity of a source of electric impulses of the proper character, and that in this manner a quantity of light sufficient to afford a practical illuminant may be produced. It is, therefore, to say the least, worth while to attempt to determine the best conditions and to invent the best appliances for attaining this object.

Some experiences have already been gained in this direction, and I will dwell on them briefly, in the hope that they might prove useful.

The heating of a conducting body inclosed in a bulb, and connected to a source of rapidly alternating electric impulses, is dependent on so many things of a different nature, that it would be difficult to give a generally applicable rule under which the maximum heating occurs. As regards the size of the vessel, I have lately found that at ordinary or only slightly differing atmospheric pressures, when air is a good insulator, and hence practically the same amount of energy by a certain potential and frequency is given off from the body, whether the bulb be small or large, the body is brought to a higher temperature if inclosed in a small bulb, because of the better confinement of heat in this case.

At lower pressures, when air becomes more or less conducting, or if the air be sufficiently warmed as to become conducting, the body is rendered more intensely incandescent in a large bulb, obviously because, under otherwise equal conditions of test, more energy may be given off from the body when the bulb is large.

At very high degrees of exhaustion, when the matter in the bulb becomes "radiant," a large bulb has still an advantage, but a comparatively slight one, over the small bulb.

Finally, at excessively high degrees of exhaustion, which cannot be reached except by the employment of special means, there seems to be, beyond a certain and rather small size of vessel, no perceptible difference in the heating.

These observations were the result of a number of experiments, of which one, showing the effect of the size of the bulb at a high degree of exhaustion, may be described and shown here, as it presents a feature of interest. Three spherical bulbs of 2 inches, 3 inches and 4 inches diameter were taken, and in the centre of each was mounted an equal length of an ordinary incandescent lamp filament of uniform thickness. In each bulb the piece of filament was fastened to the leading-in wire of platinum, contained in a glass stem sealed in the bulb; care being taken, of course, to make everything as nearly alike as possible. On each glass stem in the inside of the bulb was slipped a highly polished tube made of aluminium sheet, which fitted the stem and was held on it by spring pressure. The function of this aluminium tube will be explained subsequently. In each bulb an equal length of filament protruded above the metal tube. It is sufficient to say now that under these conditions equal lengths of filament of the same thick-

To illustrate the effect, I have here two small bulbs which are alike, only one is exhausted to a low and the other to a very high degree. When connected to the coil, the fila-

sheet is obtained. When slipped on the stem, the pressure is generally sufficient to prevent it from slipping off, but, for safety, the lower edge of the sheet may be turned in, outside of the inside corner of the sheet—that is, the outside—which is nearest to the refractory incandescent body—should be cut out diagonally, as it often happens that, in consequence of the intense heat, this corner turns toward the inside and comes very near to, or in contact with, the wire, or filament, supporting the refractory body. The greater part of the energy supplied to the bulb is then used up in heating the metal tube, and the bulb is rendered useless for the purpose. The aluminum sheet should project above the glass stem more or less—one inch or so—or else, if the glass be too close to the incandescent body, it may be strongly heated and become oxidized, thus conducting, whereupon it may be ruptured, or may, by its conductivity, establish a good electrical connection between the metal tube and the heating wire, in which case, again, most of the energy will be lost in heating the former. Perhaps the best way to make the top of the glass tube, for about an inch, of a much smaller diameter. To still further reduce the danger arising from the heating of the glass stem, and also with the view of preventing an electrical connection between the metal tube and the electrode, I preferably wrap the stem with several layers of thin mica, which extends at least as far as the metal tube. In some bulbs I have also used an outside insulating cover.

The preceding remarks are only made to aid the experimenter in the first trials, for the difficulties which he encounters he may soon find means to overcome in his own way.

To illustrate the effect of the screen, and the advantage of using it, I have here two bulbs of the same size, with their stems, leading-in wire and incandescent lamp filaments tied to the tube in nearly alike as possible. The stem of one bulb is provided with an aluminum tube, the stem of the other has none. Originally the two bulbs were joined by a tube which was connected to a Sprengel pump. When a high vacuum had been reached, first the connecting tube, and then the bulbs, were sealed off. They are therefore of the same degree of exhaustion. When they are separately connected to the coil giving a certain potential, the carbon filament in the bulb provided with the aluminum screen is rendered highly incandescent, while the filament in the other bulb may, with the same potential, not even come to redness, although in reality the latter bulb takes generally more energy than the former. When they are both connected together to the terminal, the difference is even more apparent, showing the importance of the screening. The metal tube placed on the stem containing the leading-in wire performs really two distinct functions: First, it acts more or less as an electrostatic screen, thus economizing the energy supplied to the bulb; and, second, to whatever extent it may fail to act electrostatically, it acts mechanically, preventing the bombardment, and consequently intense heating and possible deterioration of the slender support of the refractory incandescent body, or of the glass stem containing the leading-in wire. I say slender support, for it is evident that in order to confine the heat more completely to the incandescent body its support should be very thin, so as to carry away the smallest possible amount of heat by conduction. Of all the supports used I have found an ordinary incandescent lamp filament to be the best, principally because among conductors it can withstand the highest degrees of heat.

The effectiveness of the metal tube as an electrostatic screen depends largely on the degree of exhaustion. At excessively high degrees of exhaustion—which are reached by using great care and special means in connection with the Sprengel pump—when the matter in the globe is in the ultra-radiant state, it acts most perfectly. The shadow of the upper edge of the tube is then sharply defined upon the bulb.

At a somewhat lower degree of exhaustion, which is about the ordinary "non-striking" vacuum, and generally as long as the matter moves predominantly in straight lines, the screen still does well. In elucidation of the preceding remark it is necessary to state that what is a "non-striking" vacuum for a coil operated, as ordinarily, by impulses, or currents, of low frequency, is not, by far, so when the coil case the discharge may pass with great freedom through the rarefied gas through which a low-frequency discharge may not pass, even though the potential be much higher. At

electric circuit, acting as a more or less effective screen. In addition to the meaning of the word, the conducting tube or container may also act, by reason of its conductivity, as a sort of equalizer or dampener of the bombardment against the system. To be explicit, I assume the atoms of the gas to compose a rhythmic bombardment to occur again and again, the conducting tube by reason of its imperfect action as a screen, it certainly must happen that others. Those which come first strike the tube sooner than others. Those which come last, in contact with it give up their superfluous charge, and the tube is electrified, the electrification in turn spreading over its surface. But this must steadily diminish the energy lost in the bombardment for two reasons: first, the charge given up by the atoms spreads over a great area, and hence the electric density at any one point is small, and the atoms are repelled with less energy than they would be if they would strike against a good insulator; secondly, as the tube is electrified by the atoms which first come in contact with it, the progress of the following atoms against the tube is more retarded, by the repulsion which the electrified tube must exert upon the similarly electrified atoms. This repulsion may be so large as to be sufficient to prevent a large portion of the atoms from striking the tube, but at any rate it must diminish the energy of their impact. It is clear that when the exhaustion is very low, and the rarefied gas well conducting, neither of the above effects can occur, and, on the other hand, the fewer the atoms, with the greater freedom they move, in other words, the higher the degree of exhaustion, the more telling will be both the effects.

What I have just said may afford an explanation of the phenomenon observed by Prof. Crookes, namely, that a discharge through a bulb is established with much greater facility when an insulator than when a conductor is present in the same. In my opinion, the conductor acts as a dampener of the motion of the atoms in the two ways pointed out; hence, to cause a visible discharge to pass through the bulb, a much higher potential is needed if a conductor, especially of much surface, be present.

For the sake of clearness of some of the remarks before made, I must now refer to Figs. 18, 19 and 20, which illustrate various arrangements with a type of bulb most generally used.

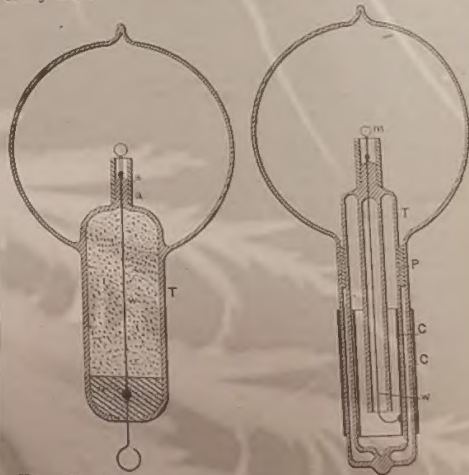


Fig. 18 is a section through a spherical bulb *L*, with the glass stem *s*, containing the leading-in wire *w*, which has a lamp filament *l* fastened to it, serving to support the refractory button *m* in the centre. *M* is a sheet of thin mica wound in several layers around the stem *s*, and *a* is the aluminium tube.

Fig. 19 illustrates such a bulb in a somewhat more advanced stage of perfection. A metallic tube *S* is fastened by means of some cement to the neck of the tube. In the tube is screwed a plug *P*, of insulating material, in the centre of which is fastened a metallic terminal *t*, for the connection to the leading-in wire *w*. This terminal must be well insulated from the metal tube *S*, therefore, if the cement used is conducting—and most generally it is sufficiently so—the space between the plug *P* and the neck of the bulb should be filled with some good insulating material, as mica powder.

Fig. 20 shows a bulb made for experimental purposes. In this bulb the aluminium tube is provided with an external connection, which serves to investigate the effect of the tube under various conditions. It is referred to chiefly to suggest a line of experiment followed.

Since the bombardment against the stem containing the leading-in wire is due to the inductive action of the latter upon the raftered gas, it is of advantage to reduce this action as far as practicable by employing a very thin wire, surrounded by a very thick insulation of glass or other material, and by making the wire passing through the raftered gas as short as practicable. To combine these features I employ a large tube T (Fig. 21), which protrudes into the bulb to some distance, and carries on the top a very short

glass stem *s*, into which is sealed the leading-in wire *w*, and I protect the top of the glass stem against the heat by a small aluminium tube *a* and a layer of mica underneath the same, as usual. The wire *w*, passing through the large tube to the outside of the bulb, should be well insulated with a glass tube, for instance—and the space between ought to be filled out with some excellent insulator. Among many insulating powders I have tried, I have found that mica powder is the best to employ. If this precaution is not taken, the tube *T*, protruding into the bulb, will surely be cracked in consequence of the heating by the brushes which are apt to form in the upper part of the tube, near the exhausted globe, especially if the vacuum be excellent, and therefore the potential necessary to operate the lamp very high.

Fig. 22 illustrates a similar arrangement, with a large tube *T* protruding into the part of the bulb containing the refractory button *m*. In this case the wire leading from the outside into the bulb is omitted, the energy required being supplied through condenser coatings *C C*. The insulating packing *P* should in this construction be tightly fitting to the glass, and rather wide, or otherwise the discharge might avoid passing through the wire *w*, which connects the inside condenser coating to the incandescent button *m*.

The molecular bombardment against the glass stem in the bulb is a source of great trouble. As illustration I will cite a phenomenon only too frequently and unwillingly observed. A bulb, preferably a large one, may be taken, be mounted in it upon a platinum wire sealed in the glass, nearly to the point when phosphorescence begins to appear. When the bulb is connected with the coil, the piece of carbon, if small, may become highly incandescent at first, but its brightness immediately diminishes, and then the discharge may break through the piece of carbon or metal at the top. The first sparks are singularly bright, recalling those drawn from a clear surface of mercury. But, as they heat the glass rapidly, they, of course, lose their brightness, and cease when the glass at the ruptured place becomes incandescent, or generally sufficiently hot to conduct. When observed for the first time the phenomenon must appear very curious, and shows in a striking manner how radically different alternate currents, or impulses, of high frequency behave, as compared with steady currents, or currents of low frequency. With such currents—namely the latter—the phenomenon would of course not occur. When frequencies such as are obtained by mechanical means are used, I think that the rupture of the glass is more or less the consequence of the bombardment, which warms it up and impairs its insulating power; but with frequencies obtainable with condensers I have no doubt that the glass may give way without previous heating. Although this appears most singular at first, it is in reality what we might expect to occur. The energy supplied to the wire leading into the bulb is given off partly by direct action through the carbon button, and partly by inductive action through the glass surrounding the wire. The case is thus analogous to that in which a condenser shunted by a conductor of low resistance is connected to a source of alternating currents. As long as the frequencies are low, the conductor gets the most, and the condenser is perfectly safe; but when the frequency becomes excessive, the role of the conductor may become quite insignificant. In the latter case the difference of potential at the terminals of the condenser may become so great as to rupture the dielectric, notwithstanding the fact that the terminals are joined by a conductor of low resistance.

It is, of course, not necessary, when it is desired to produce the incandescence of a body inclosed in a bulb by means of these currents, that the body should be a conductor, for even a perfect non-conductor may be quite as readily heated. For this purpose it is sufficient to surround a conducting electrode with a non-conducting material, as, for instance, in the bulb described before in Fig. 21, in which a thin incandescent lamp filament is coated with a non-conductor, and supports a button of the same material on the top. At the start the bombardment goes on by inductive action through the non-conductor, until the same is sufficiently heated to become conducting, when the bombardment continues in the ordinary way.

A different arrangement used in some of the bulbs constructed is illustrated in Fig. 23. In this instance a non-conductor *m* is mounted in a piece of common arc light carbon so as to project some small distance above the latter. The carbon piece is connected to the leading-in wire passing through a glass stem, which is wrapped with several layers of mica. An aluminium tube *a* is employed as usual for screening. It is so arranged that it reaches very nearly as high as the carbon and only the non-conductor *m* projects a little above it. The bombardment goes at first against the upper surface of carbon, the lower parts being protected by the aluminium tube. As soon, however, as the non-conductor *m* is heated it is rendered good conducting, and then it becomes the centre of the bombardment, being most exposed to the same.

I have also constructed during these experiments many such single-wire bulbs with or without internal electrode, in which the radiant matter was projected against, or focused upon, the body to be rendered incandescent. Fig. 24 illustrates one of the bulbs used. It consists of a spherical globe *L*, provided with a long neck *n*, on the top, for increasing the action in some cases by the application of an external conducting coating. The globe *L* is blown out on an external conducting coating. The globe *L* is blown out on the bottom into a very small bulb *b*, which serves to hold it firmly in a socket *S* of insulating material into which it is cemented. A fine lamp filament *f*, supported on a wire *w*, passes through the centre of the globe *L*. The filament is rendered incandescent in the middle portion, where the bombardment proceeding from the lower inside surface of the globe is most intense. The lower portion of the globe, as far as the socket *S* reaches, is rendered conducting, either by a thutol coating or otherwise, and the external electrode is connected to a terminal of the coil.

The arrangement diagrammatically indicated in Fig. 24 was found to be an inferior one when it was desired to render incandescent a filament or button supported in the centre of the globe, but it was convenient when the object was to excite phosphorescence.

In many experiments in which bodies of a different kind were mounted in the bulb as, for instance, indicated in Fig. 25, some observations of interest were made.

It was found, among other things, that in such cases, no matter where the bombardment began, just as soon as a high temperature was reached there was generally one of the bodies which seemed to take most of the bombardment

upon itself, the other, or others, being thereby relieved. This quality appeared to depend principally on the point of fusion, and on the facility with which the body was "evaporated," or, generally speaking, disintegrated—meaning by the latter term not only the throwing off of atoms, but likewise of larger lumps. The observation made was in accordance with generally accepted notions. In a highly exhausted bulb electricity is carried off from the electrode molecules, or lumps thrown off from the electrode. If the if one of these is more easily disintegrated than the others, and most of the electricity supplied is carried off from that body, others, and this the more, as upon an increase of the temperature the body is still more easily disintegrated.

It seems to me quite probable that a similar process takes place in the bulb even with a homogeneous electrode, and I think it to be the principal cause of the disintegration. There is bound to be some irregularity, even if the surface is highly polished, which, of course, is impossible with most of the refractory bodies employed as electrodes. Assume that a point of the electrode gets hotter, instantly most of the discharge passes through that point, and a minute patch is probably fused and evaporated. It is now possible that in consequence of the violent disintegration the spot attacked sinks in temperature, or that a counter force is created, as in an arc; at any rate, the local tearing off meets with the limitations incident to the experiment, whereupon the same process occurs on another place. To the eye the electrode appears uniformly brilliant, but there are upon it points constantly shifting and wandering around, of a temperature far above the mean, and this materially hastens the process of deterioration. That some such thing occurs, at least when the electrode is at a lower temperature, sufficient experimental evidence can be obtained in the following manner: Exhaust a bulb to a very high degree, so that with a fairly high potential the discharge cannot pass—that is, not a luminous one, for a weak invisible discharge occurs always, in all probability. Now raise slowly and carefully the potential, leaving the primary current on no more than for an instant. At a certain point, two, three, or half a dozen phosphorescent spots will appear on the globe. These places of the glass are evidently more violently bombarded than others, this being due to the unevenly distributed electric density, necessitated, of course, by sharp projections, or, generally speaking, irregularities of the electrode. But the luminous patches are constantly changing in position, which is especially well observable if one manages to produce very few, and this indicates that the configuration of the electrode is rapidly changing.

From experiences of this kind I am led to infer that, in order to be most durable, the refractory button in the bulb should be in the form of a sphere with a highly polished surface. Such a small sphere could be manufactured from a diamond or some other crystal, but a better way would be to fuse, by the employment of extreme degrees of temperature, some oxide—as, for instance, zirconia—into a small drop, and then keep it in the bulb at a temperature somewhat below its point of fusion. Interesting and useful results can no doubt be reached in the direction of extreme degrees of heat. How can such high temperatures be arrived at? How are the highest degrees of heat reached in nature? By the impact of stars, by high speeds and collisions. In a collision any rate of heat generation may be attained. In a chemical process we are limited. When oxygen and hydrogen combine, they fall, metaphorically speaking, from a definite height. We cannot go very far with a blast, nor by confining heat in a furnace, but in an exhausted bulb we can concentrate any amount of energy upon a minute button. Leaving practicability out of consideration, this, then, would be the means which, in my opinion, would enable us to reach the highest temperature. But a great difficulty when proceeding in this way is encountered, namely, in most cases the body is carried off before it can fuse and form a drop. This difficulty exists principally with an oxide such as zirconia, because it cannot be compressed in so hard a cake that it would not be carried off quickly. I endeavored repeatedly to fuse zirconia, placing it in a cup or arc light carbon as indicated in Fig. 23. It glowed with a most intense light, and the stream of the particles projected out of the carbon cup was of a vivid white; but whether it was compressed in a cake or made into a paste with carbon, it was carried off before it could be fused. The carbon cup containing the zirconia had to be mounted very low in the neck of a large bulb, as the heating of the glass by the projected particles of the oxide was so rapid that in the first trial the bulb was cracked almost in an instant when the current was turned on. The heating of the glass by the projected particles was found to be always greater when the carbon cup contained a body which was rapidly carried off—I presume because in such cases, with the same potential, higher speeds were reached, and also because, per unit of time, more matter was projected—that is, more particles would strike the glass.

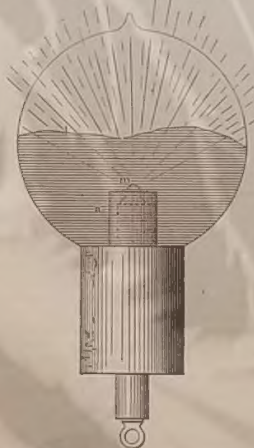


FIG. 23.—EFFECT PRODUCED BY A RUBY DROP.

The before mentioned difficulty did not exist, however, when the body mounted in the carbon cup offered great resistance to deterioration. For instance, when an oxide was first fused in an oxygen blast and then mounted in the bulb, it melted very readily into a drop.

Generally during the process of fusion magnificent light effects were noted, of which it would be difficult to give an adequate idea. Fig. 23 is intended to illustrate the effect observed with a ruby drop. At first one may see a narrow funnel of white light projected against the top of the globe, where it produces an irregularly outlined phosphorescent patch. When the point of the ruby fuses the phosphorescence becomes very powerful; but as the atoms are projected with much greater speed from the surface of the drop, soon the glass gets hot and "tired," and now only the outer edge of the patch glows. In this manner an intensely phosphorescent, sharply defined line, *l*, corresponding to the outline of the drop, is produced, which spreads slowly over the globe as the drop gets larger. When the mass begins to boil, small bubbles and cavities are formed, which cause dark colored spots to sweep across the globe. The bulb may be turned downward without fear of the drop falling off, as the mass possesses considerable viscosity.

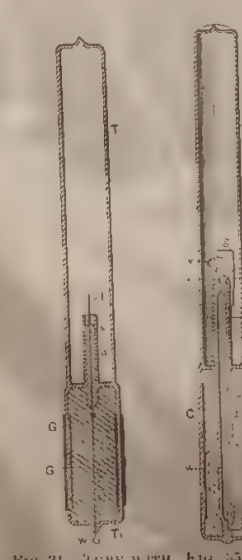
I may mention here another feature of some interest, which I believe to have noted in the course of these experiments, though the observations do not amount to a certitude. It appeared that under the molecular impact caused by the rapidly alternating potential the body was fused and maintained in that state at a lower temperature in a highly exhausted bulb than was the case at normal pressure and application of heat in the ordinary way—that is, at least, judging from the quantity of the light emitted. One of the experiments performed may be mentioned here by way of illustration. A small piece of pumice stone was stuck on a platinum wire, and first melted to it in a gas burner. The wire was next placed between two pieces of charcoal and a burner applied so as to produce an intense heat, sufficient to melt down the pumice stone into a small glass-like button. The platinum wire had to be taken of sufficient thickness to prevent its melting in the fire. While in the charcoal fire, or when held in a burner to get a better idea of the degree of heat, the button glowed with great brilliancy. The wire with the button was then mounted in a bulb, and upon exhausting the same to a high degree, the current was turned on slowly so as to prevent the cracking of the button. The button was heated to the point of fusion, and when it melted it did not, apparently, glow with the same brilliancy as before, and this would indicate a lower temperature. Leaving out of consideration the observer's possible, and even probable, error, the question is, can a body under these conditions be brought from a solid to a liquid state with evolution of less light?

When the potential of a body is rapidly alternated it is certain that the structure is jarred. When the potential is very high, although the vibrations may be few—say 20,000 per second—the effect upon the structure may be considerable. Suppose, for example, that a ruby is melted into a drop by a steady application of energy. When it forms a drop it will emit visible and invisible waves, which will be in a definite ratio, and to the eye the drop will appear to be of a certain brilliancy. Next, suppose we diminish to any degree we choose the energy steadily supplied, and, instead, supply energy which rises and falls according to a certain law. Now, when the drop is formed, there will be emitted from it three different kinds of vibrations—the ordinary visible, and two kinds of invisible waves: that is, the ordinary dark waves of all lengths, and, in addition, waves of a well defined character. The latter would not exist by a steady supply of the energy; still they help to jar and loosen the structure. If this really be the case, then the ruby drop will emit relatively less visible and more invisible waves than before. Thus it would seem that when a platinum wire, for instance, is fused by currents alternating with extreme rapidity, it emits at the point of fusion less light and more invisible radiation than it does when melted by a steady current, though the total energy used up in the process of fusion is the same in both cases. Or, to cite another example, a lamp filament is not capable of withstanding as long with currents of extreme frequency as it does with steady currents, assuming that it be worked at the same luminous intensity. This means that for rapidly alternating currents the filament should be shorter and thicker. The higher the frequency—that is, the greater the departure from the steady flow—the worse it would be for the filament. But if the truth of this remark were demonstrated, it would be erroneous to conclude that such a refractory button as used in these bulbs would be deteriorated quicker by currents of extremely high frequency than by steady or low frequency currents. From experience I may say that just the opposite holds good: the button withstands the bombardment better with currents of very high frequency. But this is due to the fact that a high frequency discharge passes through a rarefied gas with much greater freedom than a steady or low frequency discharge, and this will say that with the former we can work with a lower potential or with a less violent impact. As long, then, as the gas is of no consequence, a steady or low frequency current is better; but as soon as the action of the gas is desired and important, high frequencies are preferable.

In the course of these experiments a great many trials were made with all kinds of carbon buttons. Electrodes made of ordinary carbon buttons were decidedly more durable when the buttons were obtained by the application of enormous pressure. Electrodes prepared by depositing carbon in well known ways did not show up well; they blackened the globe very quickly. From many experiences I conclude that lamp filaments obtained in this manner can be advantageously used only with low potentials and low frequency currents. Some kinds of carbon withstand so well that, in order to bring them to the point of fusion, it is necessary to employ very small buttons. In this case the observation is rendered very difficult on account of the intense heat produced. Nevertheless there can be no doubt that all kinds of carbon are fused under the molecular bombardment, but the liquid state must be one of great instability. Of all the bodies tried there were two which withstood best—diamond and carborundum. These two showed up about equally, but the latter was preferable, for many reasons. As it is more than likely that this body is not yet generally known, I will venture to call your attention to it.

It has been recently produced by Mr. E. G. Acheson, of Monongahela City, Pa., U. S. A. It is intended to replace ordinary diamond powder for polishing precious stones, etc., and I have been informed that it accomplishes this object quite successfully. I do not know why the name "carborundum" has been given to it, unless there is something in the process of its manufacture which justifies

In Fig. 3 is illustrated another form of the bulb constructed. In this, a tube T is sealed to a globe L . The tube contains a coil C , the ends of which pass through two small glass tubes t_1 and t_2 , which are sealed to the tube T . Two refractory buttons m_1 and m_2 are mounted on lamp filaments which are fastened to the ends of the wires passing through the glass tubes t_1 and t_2 . Generally in bulbs made on this plan the globe L communicated with the tube T . For this purpose the ends of the small tubes t_1 and t_2 were just a little lifted in the burner, merely to hold the wires, but not to interfere with the communication. The tube T , with the small tubes, wires through them, and the refractory buttons m_1 and m_2 was first prepared, and then sealed to globe L , whereupon the coil C was slipped in and the connections made to its ends. The



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to the other. I pass a steady or low frequency current through the wire, and it is heated uniformly in all parts. The heating here is due to conduction, or frictional losses, and the gas around the wire has—as far as we can see—no function to perform. But now let me pass sudden discharges, or a high frequency current, through the wire. Again the wire is heated, this time principally at the ends, and least in the middle portion; and if the frequency of the impulses, or the rate of change, is high enough, the wire might as well be cut in the middle as not, for practically all the heating is due to the rarefied gas. Here the gas might only act as a conductor of an impedance diverting the current from the wire as the impedance of the latter is enormously increased, and merely heating the ends of the wire by reason of their resistance to the passage of the discharge. But it is not at all necessary that the gas in the tube should be conducting; it might be at an extremely low pressure, still the ends of the wire would be heated—is, however, as ascertained by experiment, only the two ends would in such case not be electrically connected through the gaseous medium. Now what with these frequencies and potentials occurs in an exhausted tube occurs in the lightning discharges at ordinary pressure. We only need remember one of the facts alluded to in the course of these investigations, namely, that no impulses of very high frequency the gas at a heavy pressure behaves much in the same manner as though it were at a density much less. I think that in lightning discharges frequently wires or conducting objects are utilized merely because air is present, and that, were the conductor immersed in an insulating liquid, it would be safe, for then the energy would have to spend itself somewhere else. From the behavior of gases to sudden impulses of high potential I am led to conclude that there can be no surer way of diverting a lightning discharge than by affording it a

tube was then packed with insulating powder, jamming the glass as tight as possible into the end. The end of the tube was then sealed with a small bulb, left through which the end of the tube was visible, and finally the end of the tube was closed. Usually in bulbs constructed as shown in Fig. 33 an aluminum tube a was fastened to the upper end of each of the tubes t and t_1 , in order to protect that end against the air. The buttons m and m_1 could be brought to any degree of incandescence by passing the discharge of Leyden jars at and the end C . In such bulbs with two buttons a very curious effect is produced by the formation of the shadows of each of the two buttons.

Another line of experiment, which has been assiduously followed, was to induce by electrodynamic induction a current or luminous discharge in an exhausted tube or bulb. This matter has received such able treatment at the hands of Prof. J. J. Thomson that I could add but little to what he has made known, even had I made it the special subject of this lecture. Still, some experiences in this line have gradually led me to the present views and results, a few of which must be devoted here to this subject.

It has occurred no doubt to many that as a vacuum tube is made longer the electromotive force per unit length of the tube necessary to pass a luminous discharge through the latter gets continually smaller; therefore, if the exhausted tube be made long enough, even with low frequencies a luminous discharge could be induced in such a tube closed upon itself. Such a tube might be placed around a bulb or on a ceiling and at once a simple appliance capable of giving considerable light would be obtained. But this would be an appliance hard to manufacture and extremely unmanageable. It would not do to make the tube up of small lengths, because there would be with ordinary frequencies considerable loss in the coatings, and besides, if coatings were used, it would be better to supply the current directly to the tube by connecting the coatings to a transformer. But even if all objections of such nature were removed, still, with low frequencies the light conversion itself would be inefficient, as I have before stated. In using extremely high frequencies the length of the secondary—in other words, the size of the vessel—can be reduced as far as desired, and the efficiency of the light conversion is increased, provided that means are invented for efficiently obtaining such high frequencies. Thus one is led, from theoretical and practical considerations, to the use of high frequencies, and this means high electromotive forces and small currents in the primary. When he works with condenser charges—and they are the only means up to the present known for reaching these extreme frequencies—he gets the electromotive forces of several thousands of volts per turn of the primary. He cannot multiply the electrodynamic inductive effect by taking more turns in the primary, for he arrives at the conclusion that the best way is to work with one single turn—though he must sometimes depart from this rule—and he must get along with whatever inductive effect he can obtain with one turn. But before he has long experimented with the extreme frequencies required to set up in a small bulb an electromotive force of several thousands of volts he realizes the great importance of electrostatic effects, and these effects grow relatively to the electrodynamic in significance as the frequency is increased.

Now, if anything is desirable in this case, it is to increase the frequency and this would make it still worse for the electrodynamic effects. On the other hand, it is easy to exalt the electrostatic action as far as one likes by taking more turns on the secondary, or combining self-induction and capacity to raise the potential. It should also be remembered that, in reducing the current to the smallest value and increasing the potential, the electric impulses of high frequency can be more easily transmitted through a conductor.

These and similar thoughts determined me to devote more attention to the electrostatic phenomena, and to endeavor to produce potentials as high as possible, and alternating as fast as they could be made to alternate. I then found that I could excite vacuum tubes at considerable distance from a conductor connected to a properly constructed coil, and that I could, by converting the oscillatory current of a condenser to a higher potential, establish electrostatic alternating fields which acted through the whole extent of a room, lighting up a tube no matter where it was held in space. I thought I recognized that I had made a step in advance, and I have persevered in this line; but I wish to say that I share with all lovers of science and progress the one and only desire—to reach a result of utility to men in any direction to which thought or experiment may lead me. I think that this departure is the right one, for I cannot see, from the observation of the phenomena which manifest themselves as the frequency is increased, what there would remain to act between two circuits conveying, for instance, impulses of several hundred millions per second, except electrostatic forces. Even with such trifling frequencies my conviction has grown strong that, to whatever kind of motion light may be due, it is produced by tremendous electrostatic stresses vibrating with extreme rapidity.

Of all these phenomena observed with currents, or electric impulses, of high frequency, the most fascinating for an audience are certainly those which are noted in an electrostatic field acting through considerable distance, and the best an unskilled lecturer can do is to begin and finish with the exhibition of these singular effects. I take a tube in the hand and move it about, and it is lighted wherever I may hold it; throughout space the invisible forces act. But I may take another tube and it might not light, the vacuum being very high. I excite it by means of a disruptive discharge coil, and now it will light in the electrostatic field. I may put it away for a few weeks or months, still it retains the faculty of being excited. What change have I produced in the tube in the act of exciting it? If a motion imparted to the atoms, it is difficult to perceive how it can persist so long without being arrested by frictional losses; and if a strain exerted in the dielectric, such as a simple electrification would produce, it is easy to see how it may persist indefinitely, but very difficult to understand why such a condition should not be the excitation when we have to deal with potentials which are rapidly alternating.

Since I have exhibited these phenomena for the first time, I have obtained some other interesting effects. For instance, I have produced the incandescence of a button, filament, or wire enclosed in a tube. To get to this result it was necessary to concentrate the energy which is obtained from the field and direct most of it on the small body to be rendered incandescent. At the beginning the task appeared difficult, but the experience gathered permitted me to reach the result easily. In Fig. 34 and Fig. 35 two such tubes are illustrated which are prepared for the occasion. In Fig.

34 a short tube T , sealed to another long tube L , is provided with a stem s , with a platinum wire sealed in the latter. A very thin lamp filament f is fastened to this wire, and connection to the outside is made through a thin copper wire w . The tube is provided with outside and inside coatings, C and C' respectively, and is filled as far as possible with insulating powder. These coatings are merely used to enable me to perform two experiments with the tube, namely, to produce the effect desired either by direct connection of the body of the experimenter or of another body to the wire w , or by acting inductively through the glass. The stem s is provided with an aluminum tube a , for purposes before explained, and only a small part of the filament reaches out of this tube. By holding the tube L anywhere in the electrostatic field the filament is rendered incandescent.

A more interesting piece of apparatus is illustrated in Fig. 35. The construction is the same as before, only instead of the lamp filament a small platinum wire p , sealed in a stem s , and bent above it in a circle, is connected to the copper wire w , which is joined to an inside coating C . A small stem s_1 is provided with a needle, on the point of which is arranged to rotate very freely a very light fan of mica g . To prevent the fan from falling out, a thin stem of glass g_1 is bent properly and fastened to the aluminum tube. When the glass tube is held anywhere in the electrostatic field the platinum wire becomes incandescent, and the mica vanes are rotated very fast.

Intense phosphorescence may be excited in a bulb by merely connecting it to a plate within the field, and the plate need not be any larger than an ordinary lamp shade. The phosphorescence excited with these currents is incomparably more powerful than with ordinary apparatus. A small phosphorescent bulb, when attached to a wire connected to a coil, emits sufficient light to allow reading ordinary print at a distance of five to six paces. It was of interest to see how some of the phosphorescent bulbs of Professor Crookes would behave with these currents, and he has had the kindness to lend me a few for the occasion. The effects produced are magnificent, especially by the sulphide of calcium and sulphide of zinc. From the disruptive discharge coil they glow intensely merely by holding them in the hand and connecting the body to the terminal of the coil.

To whatever results investigations of this kind may lead, their chief interest lies for the present in the possibilities they offer for the production of an efficient illuminating device. In no branch of electric industry is an advance more desired than in the manufacture of light. Every thinker, when considering the barbarous methods employed, the deplorable losses incurred in our best systems of light production, must have asked himself, What is likely to be the light of the future? Is it to be an incandescent solid, as in the present lamp, or an incandescent gas, or a phosphorescent body, or something like a burner, but incomparably more efficient?

There is little chance to perfect a gas burner; not, perhaps, because human ingenuity has been bent upon that problem for centuries without a radical departure having been made—though this argument is not devoid of force—but because in a burner the higher vibrations can never be reached except by passing through all the low ones. For how is a flame produced unless by a fall of lifted weights? Such process cannot be maintained without renewal, and renewal is repeated passing from low to high vibrations. One way only seems to be open to improve a burner, and that is by trying to reach higher degrees of incandescence. Higher incandescence is equivalent to a quicker vibration; that means more light from the same material, and that, again, means more economy. In this direction some improvements have been made, but the progress is hampered by many limitations. Discarding, then, the burner, there remain the three ways first mentioned, which are essentially electrical.

Suppose the light of the immediate future to be a solid rendered incandescent by electricity. Would it not seem that it is better to employ a small button than a frail filament? From many considerations it certainly must be concluded that a button is capable of a higher economy, assuming, of course, the difficulties connected with the operation of such a lamp to be effectively overcome. But to light such a lamp we require a high potential; and to get this economically we must use high frequencies.

Such considerations apply even more to the production of light by the incandescence of a gas, or by phosphorescence. In all cases we require high frequencies and high potentials. These thoughts occurred to me a long time ago.

Incidentally we gain, by the use of very high frequencies, many advantages, such as a higher economy in the light production, the possibility of working with one lead, the possibility of doing away with the leading-in wire, etc.

The question is, how far can we go with frequencies? Ordinary conductors rapidly lose the facility of transmitting electric impulses when the frequency is greatly increased. Assume the means for the production of impulses of very great frequency brought to the utmost perfection, every one will naturally ask how to transmit them when the necessity arises. In transmitting such impulses through conductors we must remember that we have to deal with pressure and flow, in the ordinary interpretation of these terms. Let the pressure increase to an enormous value, and let the flow correspondingly diminish, then such impulses—variations merely of pressure, as it were—can no doubt be transmitted through a wire even if their frequency course, be out of question to transmit such impulses through a wire immersed in a gaseous medium, even if the wire were provided with a thick and excellent insulation, for most of the energy would be lost in molecular bombardment and consequent heating. The end of the wire connected to the source would be heated, and the remote end would receive but a trifling part of the energy supplied. The prime necessity, then, if such electric impulses are to be used, is to find means to reduce as much as possible the dissipation.

The first thought is, employ the thinnest possible wire surrounded by the thickest practicable insulation. The next thought is to employ electrostatic screens. The insulation of the wire may be covered with a thin conducting coating and the latter connected to the ground. But this would not do, as then all the energy would pass through the conducting coating to the ground and nothing would get to the end of the wire. If a ground connection is made it can only be made through a conductor offering an enormous impedance, or through a condenser of extremely small capacity. This, however, does not do away with other difficulties.

If the wave length of the impulses is much smaller than the length of the wire, then corresponding short waves will be sent up in the conducting coating, and it will be

more or less the same as though the coating were connected to earth. It is therefore much shorter than the coating in section, much shorter than the coating in length. Such an arrangement does not still afford a perfect screen, but it is ten thousand times better than none. I think it preferable to cut up the conducting coating in small sections, even if the current waves be much longer than the coating.

If a wire were provided with a perfect electrostatic screen, it would be the same as though all objects were removed from it at infinite distance. The capacity would then be reduced to the capacity of the wire itself, which would be very small. It would then be possible to send over the wire current vibrations of very high frequencies at enormous distance without affecting greatly the character of the vibrations. A perfect screen is of course out of the question, but I believe that with a screen such as I have just described telephony could be rendered practicable across the Atlantic. According to my ideas, the gutta-percha covered wire should be provided with a third conducting coating subdivided in sections. On the top of this should be again placed a layer of gutta-percha and other insulation, and on the top of the whole the armor. But such cables will not be constructed, for the long intelligence—transmitted without wires—will trouble enough the earth like a pulse through a living organism. The wonder is that, with the present state of knowledge and the experiences gained, no attempt is being made to disturb the electrostatic or magnetic condition of the earth, and transmit, if nothing else, intelligence.

It has been my chief aim in presenting these results to point out phenomena or features of novelty, and to advance ideas which I am hopeful will serve as starting points of new departures. It has been my chief desire this evening to entertain you with some novel experiments. Your applause, so frequently and generously accorded, has told me that I have succeeded.

In conclusion, let me thank you most heartily for your kindness and attention and assure you that the honor I have had in addressing such a distinguished audience, the pleasure I have had in presenting these results to a gathering of so many able men—and among them also some of those in whose work for many years past I have found enlightenment and constant pleasure—I shall never forget.

NEW BOOKS.

CONTINENTAL ELECTRIC LIGHT CENTRAL STATIONS, with Notes on the Methods in Actual Practice for Distributing Electricity in Towns. By Killingsworth Hodges. 210 pp., 25 plates and numerous illustrations. Price, \$6.00. E. & F. N. Spon: London, 1892.

The object of the author of this book is first to enable the members of lighting committees and others taking up the question of the introduction of electricity to attain a rapid survey of what has been done abroad both on a large and a small scale, and consequently to enable electrical engineers to follow those arrangements for distributing electricity which differ from the usual English practice. It is compiled in part from the reports made for the Congress of the German municipal authorities on the occasion of their visit to the International Electrical Exhibition at Frankfurt in August of last year.

There is probably no other country in the world where there is a greater variety of systems in use in central stations than in Germany and other continental countries of Europe. There appear to be scarcely two stations alike. It is to acquaint the electrical engineer and others interested in central stations with these very varied systems that the author has prepared this volume. As the Americans are perhaps even less well acquainted with the methods used in continental Europe than the Englishmen are, this book ought to be of great interest to Americans, as it will undoubtedly be to the English.

The general plan of the book is a more or less complete description of each of about 57 different central stations on the continent. They are divided into two parts, the first one on high pressure distribution with alternating currents and transformers, and the second on low pressure distribution by continuous currents, either direct or with secondary batteries. By far the larger number are comprised in Part 2. Part 3 is devoted to a number of different subjects, including a description of the Lauffen-Frankfurt power transmission plant, electrical measuring instruments, conduits, electricity compared with gas, load factors, network of mains, interest of gas companies with regard to electric lighting, continental central station practice, cost of electric light abroad and relative cost of electricity, concluding with some tables and other similar information of like nature, including a short glossary of technical terms.

This volume is provided throughout with a very large number of well-selected illustrations, including many large plates of plans of these stations, together with views, chiefly of the internal arrangement of the stations and of machines, switchboards and other apparatus.

It is well known that German engineers are perhaps the most thorough of those of any country, and therefore the results of their work, so well illustrated in the descriptions of these stations, cannot fail to be not only of interest but also of instruction to many American engineers.

The language used and the character of the illustrations is such that the book can be read and understood not only by the engineer but also by managers, capitalists and others interested in central station lighting. Some of the stations described use systems which are perhaps scarcely known in America, although they have been in use successfully in Europe for some time.

HISTORY OF THE WEST END STREET RAILWAY, BOSTON, MASS., together with Speeches by President Henry M. Whitney and others; also Expert Testimony as to the Safety of Electric Currents. By Louis P. Hager. 206 pp., ill. Published by the author. Price, \$1. Boston.

This is a very complete historical account of the development of the street railway system, and especially of the electric railway in Boston. As is well known the entire street railway system in and around the city of Boston is controlled by one corporation, namely the West End Street Railway Company, of which Mr. Henry M. Whitney is president. The volume before us contains the most detailed account of the electric railway installations of the West End system, that we have seen. It is interesting to notice that the first street railway corporation to receive a charter from the Massachusetts Legislature was the North Street & Roxbury Company, which obtained its franchise in 1832. Those who wish to obtain detailed information regarding the various kinds of apparatus used in the electrical installation of the West End system will not be disappointed if they search for it in Mr. Hager's book.

always keep the reservoirs in fine condition, and the mercury was never withdrawn from R_1 except when the pump had reached the highest degree of exhaustion. It is necessary to observe this rule if it is desired to use the apparatus to advantage.

By means of this arrangement I was able to proceed very quickly, and when the apparatus was in perfect order it was possible to reach the phosphorescent stage in a small bulb in less than 15 minutes, which is certainly very quick work for a small laboratory arrangement requiring all in all about 100 pounds of mercury. With ordinary small bulbs the ratio of the capacity of the pump, receiver, and connections, and

space filled with oil, the loss would be incomparably smaller than when the fluid is replaced by a gas, for in the latter case the force produces displacements; that means impact and collisions in the inside.

No matter what the pressure of the gas may be, it becomes an important factor in the heating of a conductor when the electric density is great and the frequency very high. That in the heating of conductors by lightning discharge, air is an element of great importance, is almost as certain as an experimental fact. I may illustrate the action of the air by the following experiment: I take a short tube which is exhausted to a moderate degree and has a platinum wire running through the middle from one end

to the other. As the bombardment goes on, it is more heated than other points, finally practically all the discharges are concentrated at the point which is intensely heated. The stream is composed of particles (Fig. 31) then breaks up into a stream of particles. But the point because the velocity imparted due to three causes—to the great temperature of the small particles of the lime are easily to be obtained, the particles are able to obtain, the particles are projected to a considerable distance. Only a stress would spread or gated through the bulb. It reaches any such frequency atoms move with the speed of a thing is impossible; for would be required. With particles obtain, even with a disruption must be quite insignificant.

As to the "non-striking" is that it can occur only with it is necessitated by the impossibility of energy with such impulses in atoms which are around the fact with the same are repelled comparatively long period can be performed to render eye. If the difference of potential is raised, the dielectric breakdown frequency impulses there is down, since any amount of continually agitating the atoms in the frequency is high enough with frequencies obtained from a stage at which the discharge electrodes in a narrow tube, to one of the terminals of the a point at which a luminous around each electrode.

A thought which naturally with high frequency current, powerful electro-dynamic induction effects in a sealed glass globe of the defects of the present other improvement were made should be done away with, carried on experiments in some were indicated in my mention one or two more lines been followed up.

Many bulbs were constructed Fig. 33.

In Fig. 32 a wide tube T shaped tube U , of phosphorus was placed a coil C of aluminum were provided with small electrodes and reached into the U tube a socket containing a plug

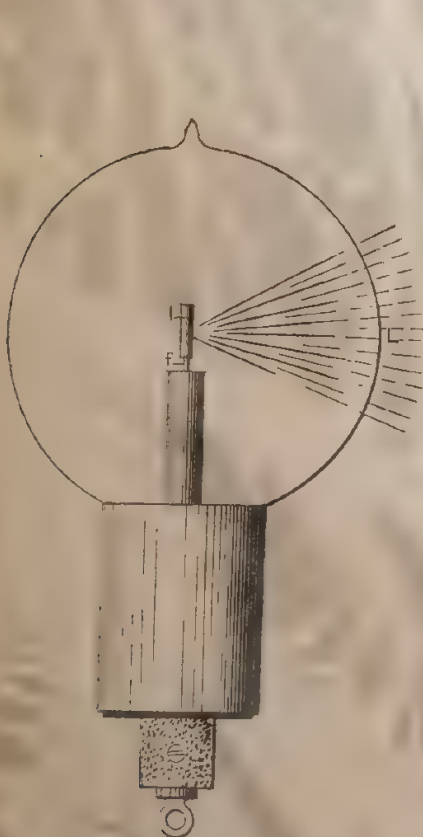


FIG. 31.—BULB SHOWING RADIANT LIME STREAM AT LOW EXHAUSTION.

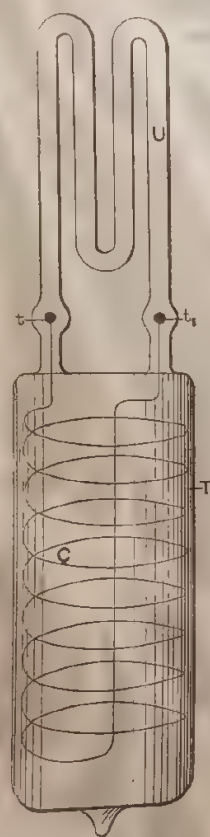


FIG. 32.—ELECTRO-DYNAMIC INDUCTION TUBE.

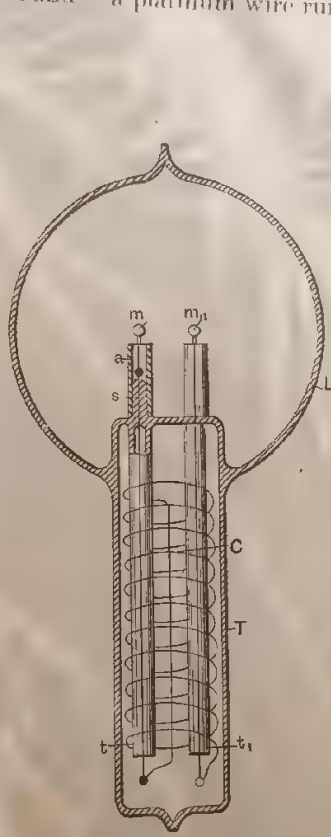


FIG. 33.—ELECTRO-DYNAMIC INDUCTION LAMP.

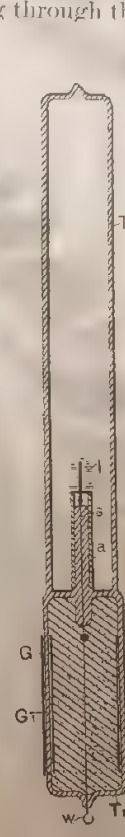


FIG. 34.—TUBE WITH FILAMENT RENDERED INCANDESCENT.

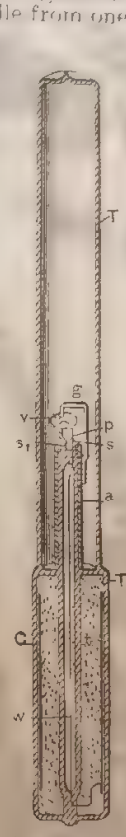


FIG. 35.—EXPERIMENT IN ELECTROSTATIC FIELD.

that of reservoir R was about 1-20, and the degrees of exhaustion reached were necessarily very high, though I am unable to make a precise and reliable statement how far the exhaustion was carried.

What impresses the investigator most in the course of these experiences is the behavior of gases when subjected to great rapidly alternating electrostatic stresses. But he must remain in doubt as to whether the effects observed

to the other. I pass a steady or low frequency current through the wire, and it is heated uniformly in all parts. The heating here is due to conduction, or frictional losses, and the gas around the wire has—as far as we can see—no function to perform. But now let me pass sudden discharges, or a high frequency current, through the wire. Again the wire is heated, this time principally on the ends and least in the middle portion; and if the frequency of the and least in the middle portion, and if the frequency of the and least in the middle portion, and if the frequency of the

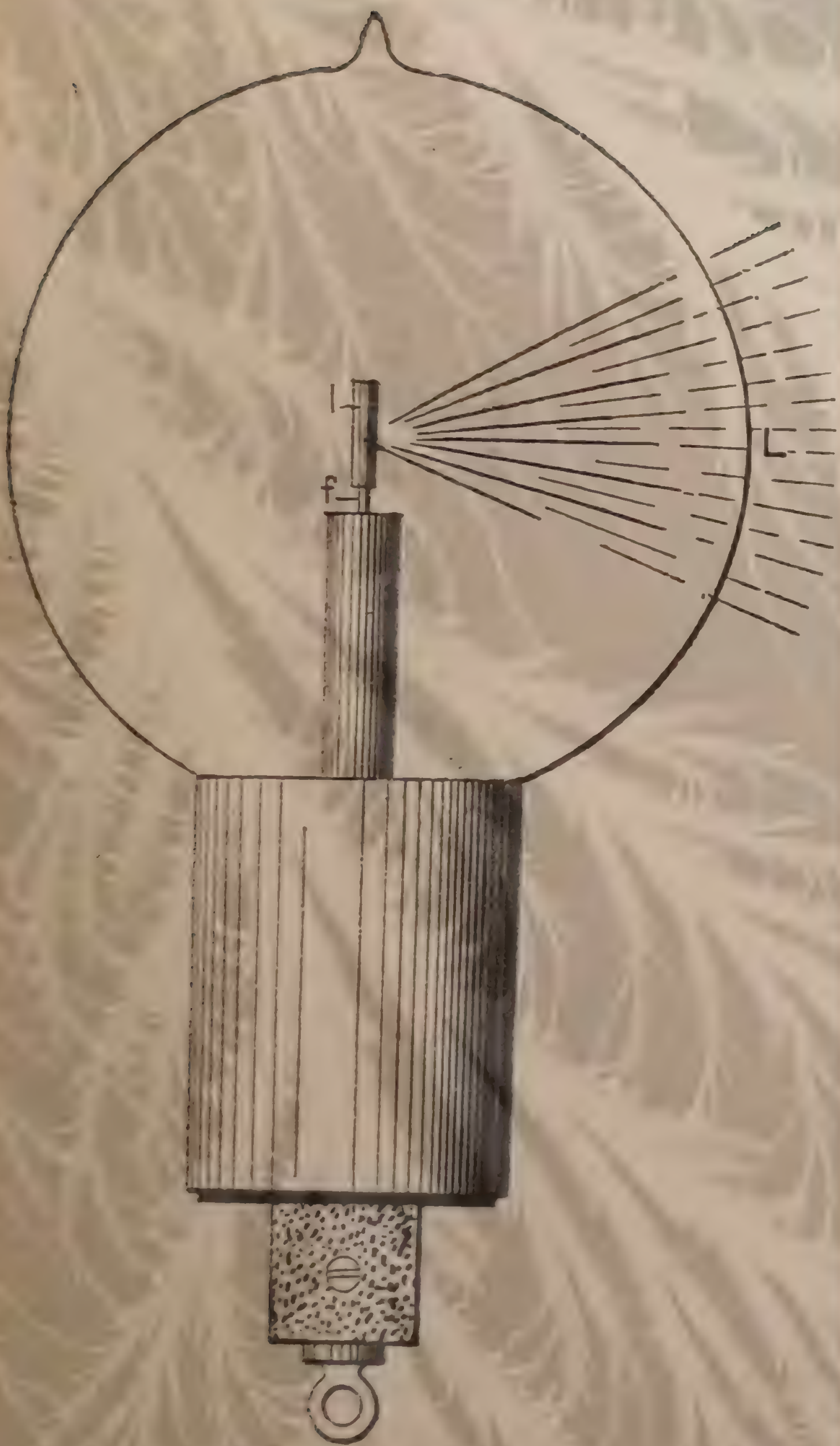


FIG. 31.—BULB SHOWING RA-
DIANT LIME STREAM AT
LOW EXHAUSTION.

FIG

always keep the mercury and both the reservoirs in fine condition, and the mercury was never withdrawn from R_1 except when the pump had reached the highest degree of exhaustion. It is necessary to observe this rule if it is desired to use the apparatus to advantage.

By means of this arrangement I was able to proceed very quickly, and when the apparatus was in perfect order it was possible to reach the phosphorescent stage in a small bulb in less than 15 minutes, which is certainly very quick work for a small laboratory arrangement requiring all in all about 100 pounds of mercury. With ordinary small bulbs the ratio of the capacity of the pump, receiver, and connections, and

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discharge is very rapidly alternating. Even were the sphere filled with oil, the loss would be incomparably smaller than when the fluid is replaced by a gas, for in the latter case the force produces displacements; that means impact and collisions in the inside. No matter what the pressure of the gas may be, it becomes an important factor in the heating of a conductor when the electric density is great and the frequency very high. That in the heating of conductors by lightning discharges air is an element of great importance, is almost as certain as an experimental fact. I may illustrate the action of the air by the following experiment: I take a short tube which is exhausted to a moderate degree and has a platinum wire running through the middle from one end

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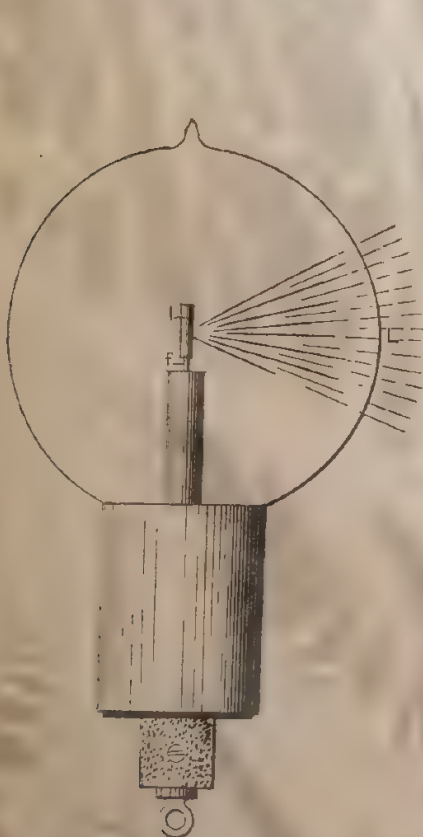


FIG. 31.—BULB SHOWING RADIANT LIME STREAM AT LOW EXHAUSTION.

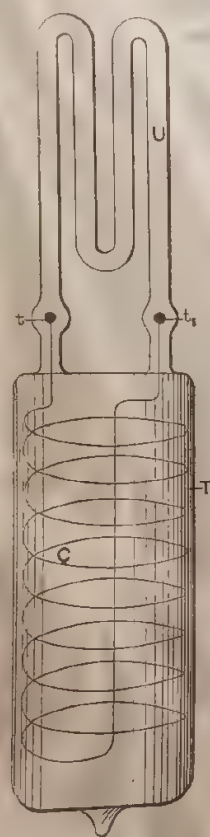


FIG. 32.—ELECTRO-DYNAMIC INDUCTION TUBE.

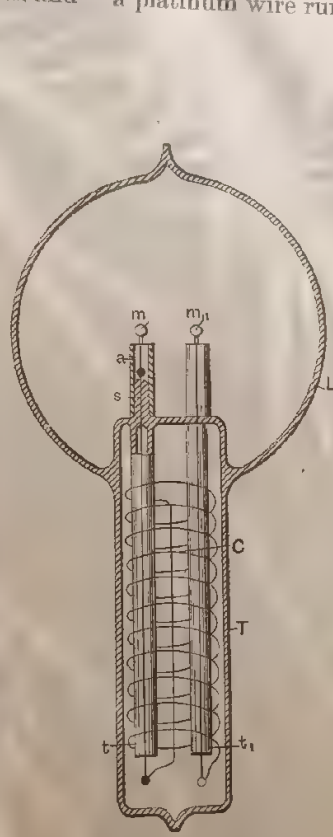


FIG. 33.—ELECTRO-DYNAMIC INDUCTION LAMP.

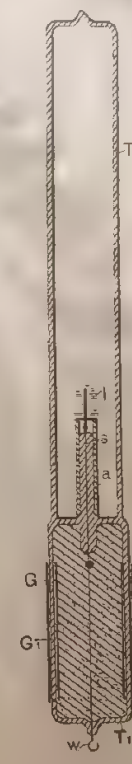


FIG. 34.—TUBE WITH FILAMENT RENDERED INCANDESCENT.

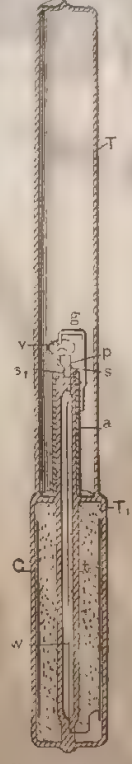


FIG. 35.—EXPERIMENT IN ELECTROSTATIC FIELD.

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What impresses the investigator most in the course of these experiences is the behavior of gases when subjected to great rapidly alternating electrostatic stresses. But he must not be misled by the effects observed

raised above the surface of the tube when the effects observed always keep the mercury and both the reservoirs in fine condition, and the mercury was never withdrawn from R_1 except when the pump had reached the highest degree of exhaustion. It is necessary to observe this rule if it is desired to use the apparatus to advantage.

By means of this arrangement I was able to proceed very quickly, and when the apparatus was in perfect order it was possible to reach the phosphorescent stage in a small bulb in less than 15 minutes, which is certainly very quick work for a small laboratory arrangement requiring all in all about 100 pounds of mercury. With ordinary small bulbs the ratio of the capacity of the pump, receiver, and connections, and

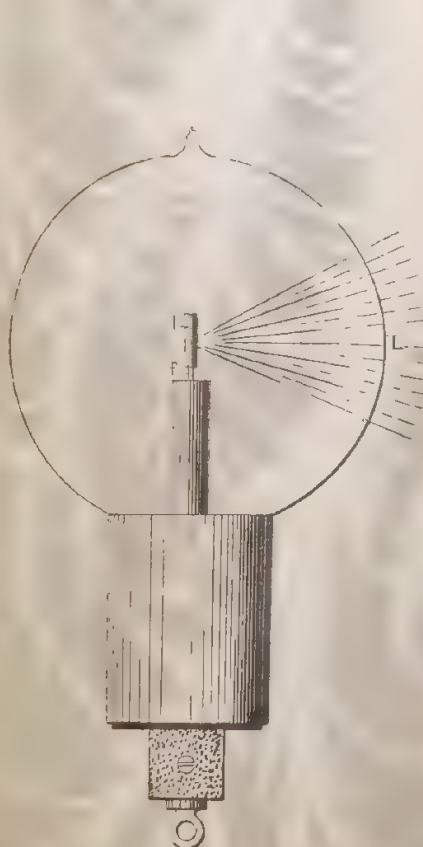


FIG. 31.—BULB SHOWING RADIANT LIME STREAM AT LOW EXHAUSTION.

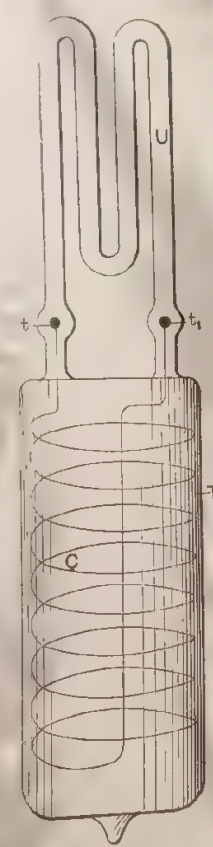


FIG. 32.—ELECTRO-DYNAMIC INDUCTION TUBE.

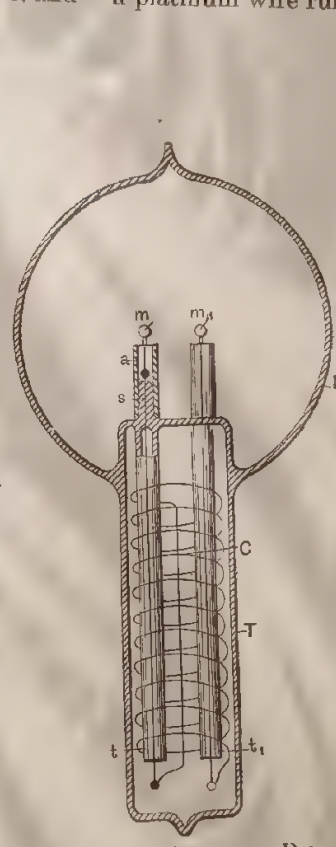


FIG. 33.—ELECTRO-DYNAMIC INDUCTION LAMP.



FIG. 34.—TUBE WITH FILAMENT RENDERED INCANDESCENT.

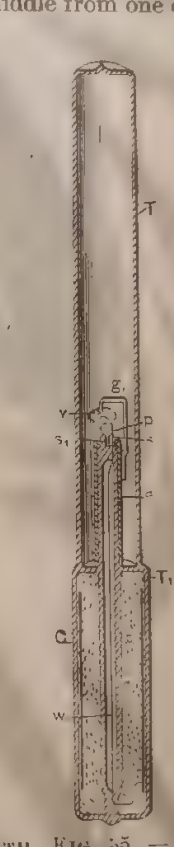


FIG. 35.—EXPERIMENT IN ELECTROSTATIC FIELD.

at e was heated and the terglobe L was exhausted is charge to pass through, as appeared crimson, pro- cases, when the exhaust- the air good conducting, to bring the button m to ferably on the upper part coating which was con- e ground, or to the other- ly conducting air weak- ly by being acted upon re it entered the bulb at ver, is always present nted in a very small bulb rated in Fig. 29, namely, be impaired in a com-

ribed constructions was portion of the globe by An advantage is secured, ide bulb and slow evap- hard to maintain, even Fig. 28 be chosen, in

way—would be to reach higher the frequency of the air, and I think t which there would be ecules around the ter- flame in which there rial, and a queer flame

With such high fre- would come into play, rigidity in virtue of the e of the latter would ly occur, for, the un- id, the potential energy- ly only atomic vibra- of translation through an ordinary gas burner nating potential might tam limit, and this for al vibration imparted, e process of carrying difficult, and renewal burner, a continued in- pulses, assuming they ed upon the flame, he latter, meaning by emical process.

of an electrode im- and surrounded by es, which can be acted frequency of the im- itation of the gas all his it would be only ependent bodies are urn toward the elec- ic density, and this id resistance to ap- ered to the receding, is that it is out of the as might—assuming be true—produce any as mere possibilities, these investigations, ena I have gained

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minutes, using glowing... often varied perceptibly, and it could be observed that the electrostatic attraction of the glass affected the vibrating thread; but it was clear that the electrostatic action was not the cause of the vibration, for the thread was most generally stationary, and could always be set in vibration by passing the finger quickly near the upper part of the tube. With a magnet the thread could be split in two and both parts vibrated. By approaching the hand to the lower coating of the tube, or insulated plate if attached, the vibration was quickened; also, as far as I could see, by raising the potential or frequency. Thus, either increasing the frequency or passing a stronger discharge of the same frequency corresponded to a tightening of the cord. I did not obtain any experimental evidence with condenser discharges. A luminous band excited in a bulb by repeated discharges of a Leyden jar must

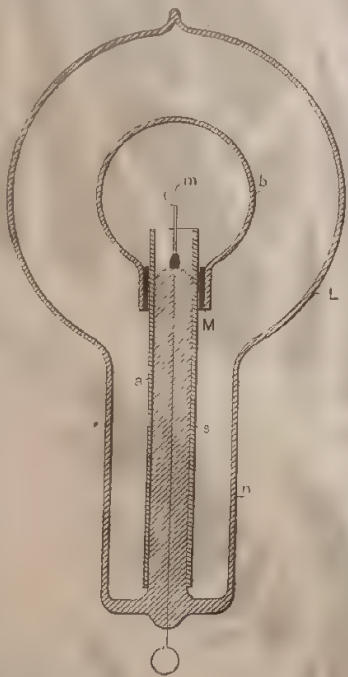


FIG. 28.—LAMP WITH AUXILIARY BULB FOR CONFINING THE ACTION TO THE CENTRE.

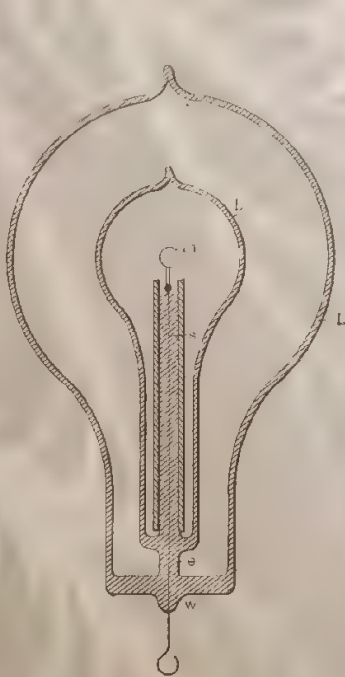


FIG. 29.—LAMP WITH INDEPENDENT AUXILIARY BULB.

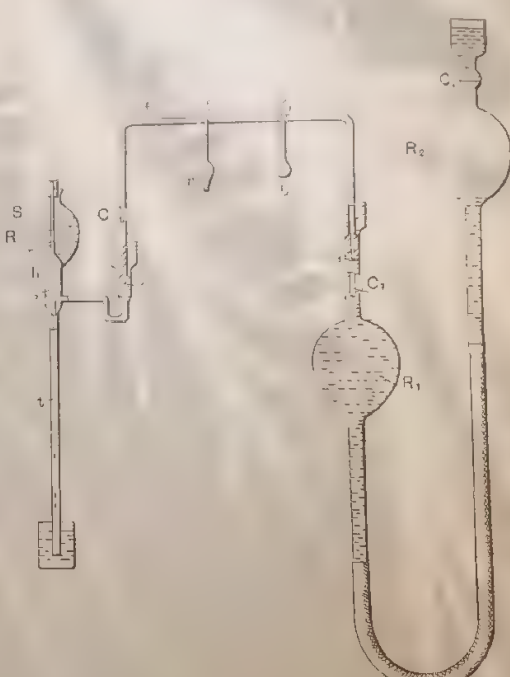


FIG. 30.—APPARATUS USED FOR OBTAINING HIGH DEGREES OF EXHAUSTION.

possess rigidity, and if deformed and suddenly release should vibrate. But probably the amount of vibrating matter is so small that in spite of the extreme speed the inertia cannot prominently assert itself. Besides, the observation in such a case is rendered extremely difficult on account of the fundamental vibration.

The demonstration of the fact—which still needs better experimental confirmation—that a vibrating gaseous column possesses rigidity, might greatly modify the views of thinkers. When with low frequencies and insignificant potentials indications of that property may be noted, how must a gaseous medium behave under the influence of enormous electrostatic stresses which may be active in the inter-

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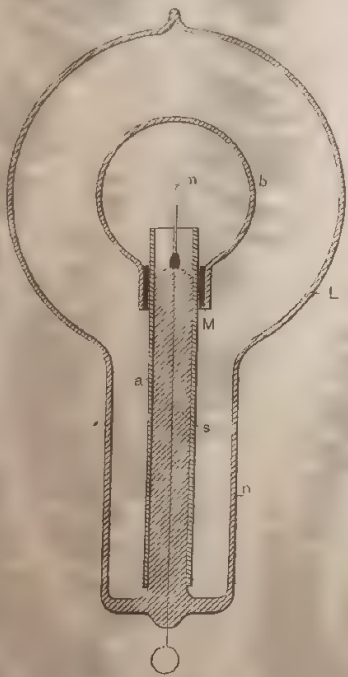


FIG. 28. LAMP WITH AUXILIARY BULB FOR CONFINING THE ACTION TO THE CENTRE.

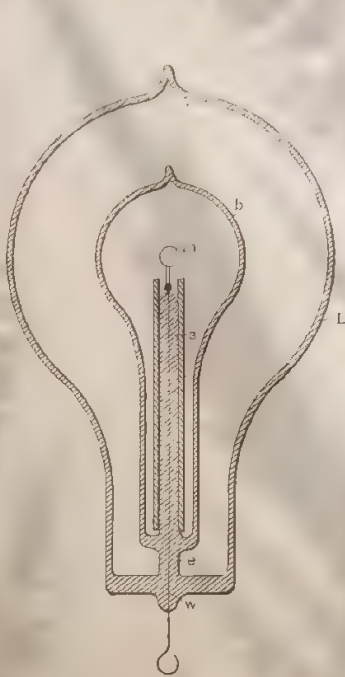


FIG. 29.—LAMP WITH INDEPENDENT AUXILIARY BULB.

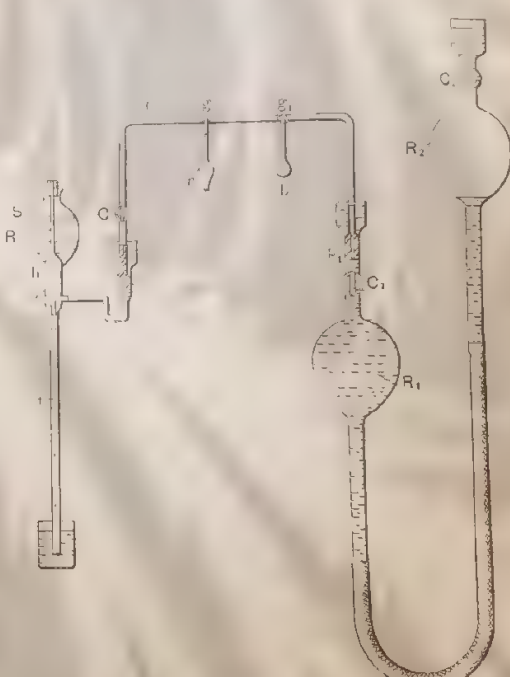


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specially... stop-cock which is usually employed has been omitted, and instead of it a hollow stopper s has been fitted in the neck of the reservoir R . This stopper has a small hole h , through which the mercury descends; the size of the outlet o being properly determined with respect to the section of the fall tube t , which is sealed to the reservoir instead of being connected to it in the usual manner. This arrangement overcomes the imperfections and troubles which often arise from the use of the stopcock on the reservoir and the connection of the latter with the fall tube.

The pump is connected through a J-shaped tube t to a very large reservoir R_1 . Especial care was taken in fitting the grinding surfaces of the stoppers p and p_1 , and both of these and the mercury caps above them were made exceptionally long. After the U-shaped tube was fitted and put

in place, it was heated, so as to soften and take off the strain resulting from imperfect fitting. The U-shaped tube was provided with a stopcock C , and two ground connections g and g_1 —one for a small bulb b , usually containing caustic potash, and the other for the receiver r , to be exhausted.

The reservoir R_1 was connected by means of a rubber tube to a slightly larger reservoir R_2 , each of the two reservoirs being provided with a stopcock C_1 and C_2 , respectively. The reservoir R_2 could be raised and lowered by a wheel and rack, and the range of its motion was so determined that when it was filled with mercury and the

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was sprinkled low temperature upon reservoir sealed up.

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desired to use By means c quickly, and possible to re in less than 1 for a small la 100 pounds o of the capaci

FIG. 31.—DIAPHRAGM LOW R

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...the energy, probably only
little of the energy of the vibrations set up would be lost
into space in the form of long ether radiations, but most of
the energy, I think, would spend itself in molecular im-
pacts and collisions, and pass off into space in the form of
short heat, and possibly light, waves. As both the fre-
quency of the vibrations of the charge and the potential are
in all probability excessive, the energy converted into heat
may be considerable. Since the density must be unevenly
distributed, either in consequence of the irregularity of the
earth's surface, or on account of the condition of the at-
mosphere in various places, the effect produced would ac-
cordingly vary from place to place. Considerable varia-
tions in the temperature and pressure of the atmosphere
may in this manner be caused at any point of the surface
of the earth. The variations may be gradual or very sud-

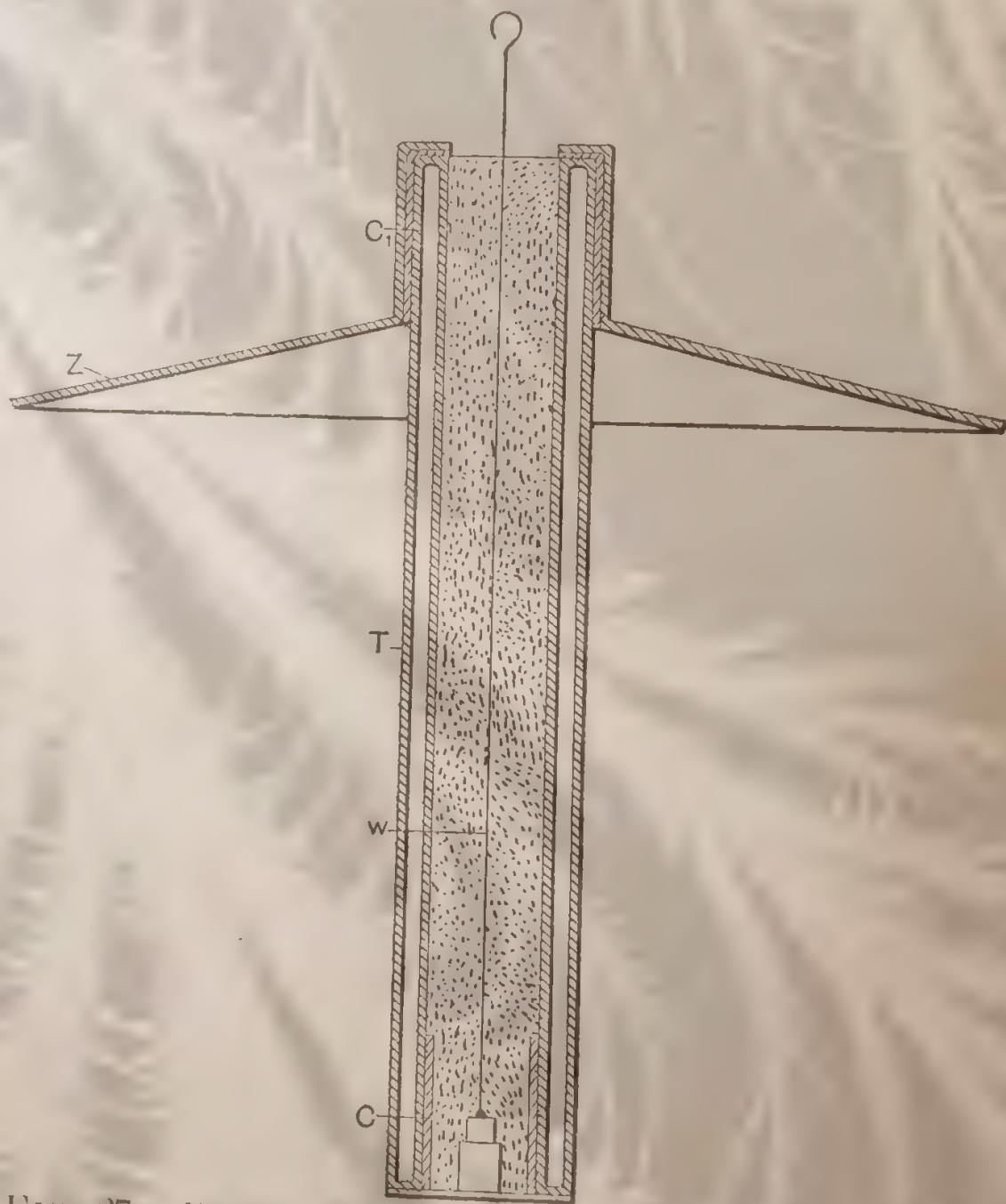


FIG. 27.—PHOSPHORESCENT TUBE WITH INTENSIFYING REFLECTOR.

den, according to the nature of the general disturbance, and may produce rain and storms, or locally modify the weather in any way.

From the remarks before made one may see what an im-
portant factor of loss the air in the neighborhood of a
charged surface becomes when the electric density is great
and the frequency of the impulses excessive. But the
action as explained implies that the air is insulating—that
is, that it is composed of independent carriers immersed in
an insulating medium. This is the case only when the air
is at something like ordin-

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by a thick insulation from the end of wire *w*.

The economical use of such a reflector or intensifier would require that all energy supplied to an air condenser should be recoverable, or, in other words, that there should not be any losses, neither in the gaseous medium nor through its action elsewhere. This is far from being so, but, fortunately, the losses may be reduced to anything desired. A few remarks are necessary on this subject, in order to make the experiences gathered in the course of these investigations perfectly clear.

Suppose a small helix with many well insulated turns, as in experiment Fig. 17, has one of its ends connected to one

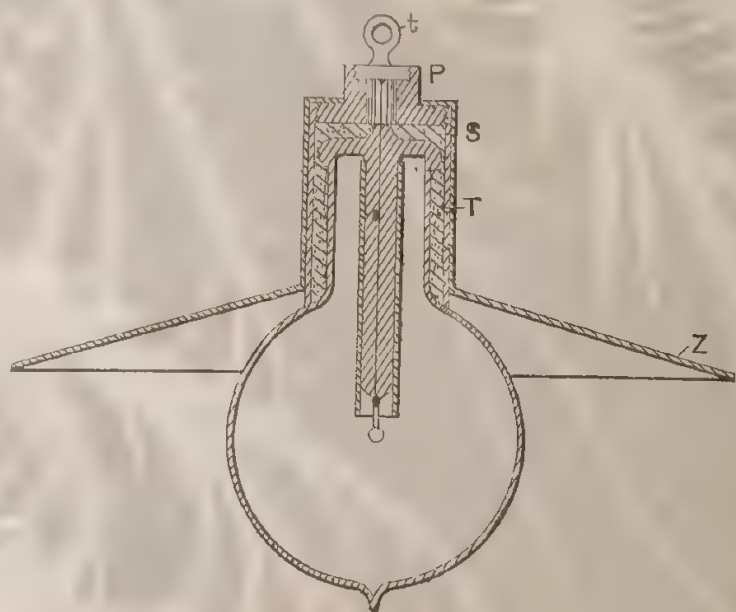


FIG. 26.—IMPROVED BULB WITH INTENSIFYING REFLECTOR.

of the terminals of the induction coil, and the other to a metal plate, or, for the sake of simplicity, a sphere, insulated in space. When the coil is set to work, the potential of the sphere is alternated, and the small helix now behaves as though its free end were connected to the other terminal of the induction coil. If an iron rod be held within the small helix it is quickly brought to a high temperature, indicating the passage of a strong current through

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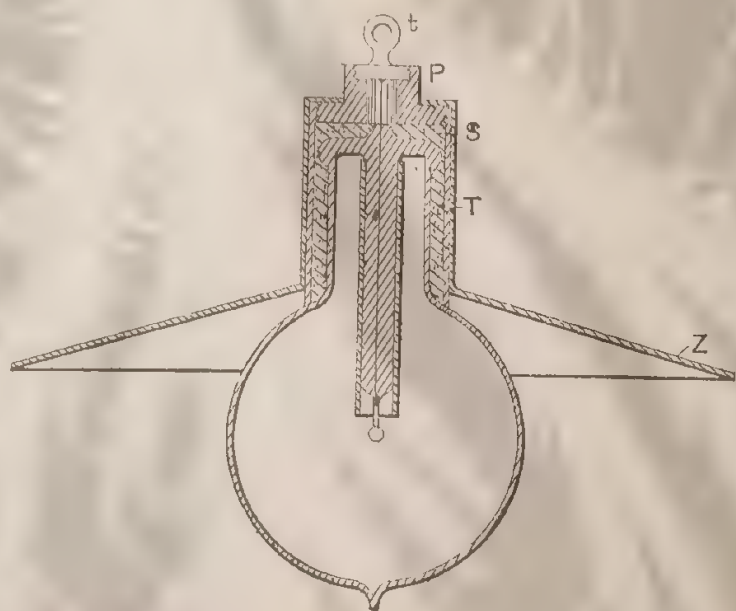


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It should not be thought that t condenser is necessarily associat visible streams or brushes. If a in an unexhausted bulb, is con minals of the coil, streams can electrode and the air in the bulb small electrode, a large sphere streams are observed, still the a

Nor should it be thought that condenser would give even an loss in heat incurred, as in suc off much more quickly, since ordinary radiation, a very active independent carriers going on, paratus, but the air at some di consequence of the collisions v

Owing to this, in experiment temperature can be distinctly connected to the coil is very st a larger scale, even a body of heated, as, for instance, the b that skilled physicians might in such experiments, which, ciously designed, would not p

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In all these experiments the action was intensified by augmenting the capacity at the end of the lead connected to the terminal. As a rule, it is not necessary to resort to

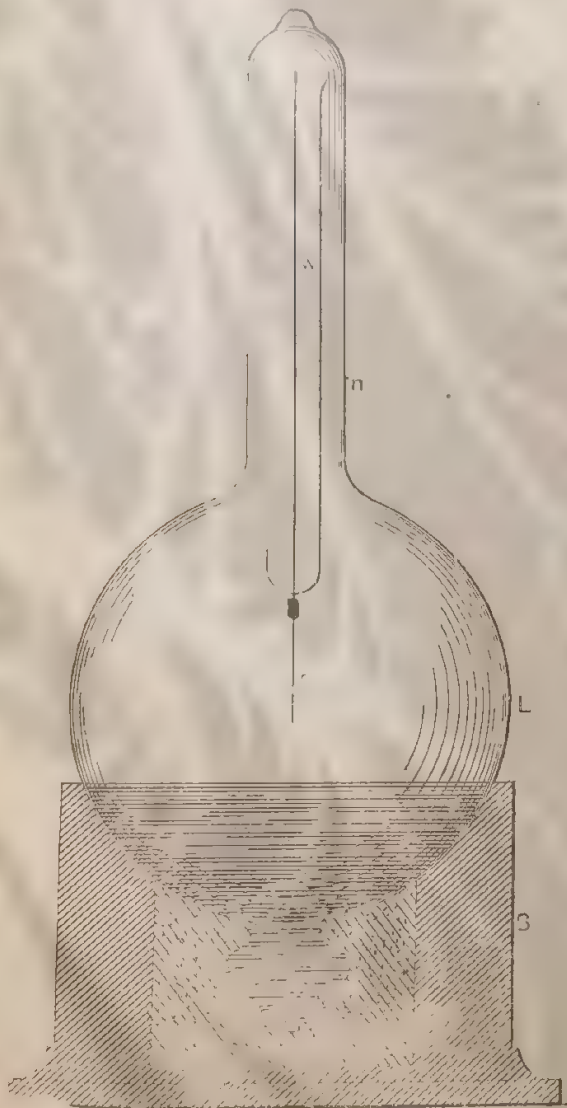


FIG. 24.—BULB WITHOUT LEADING-IN WIRE, SHOWING EFFECT OF PROJECTED MATTER.

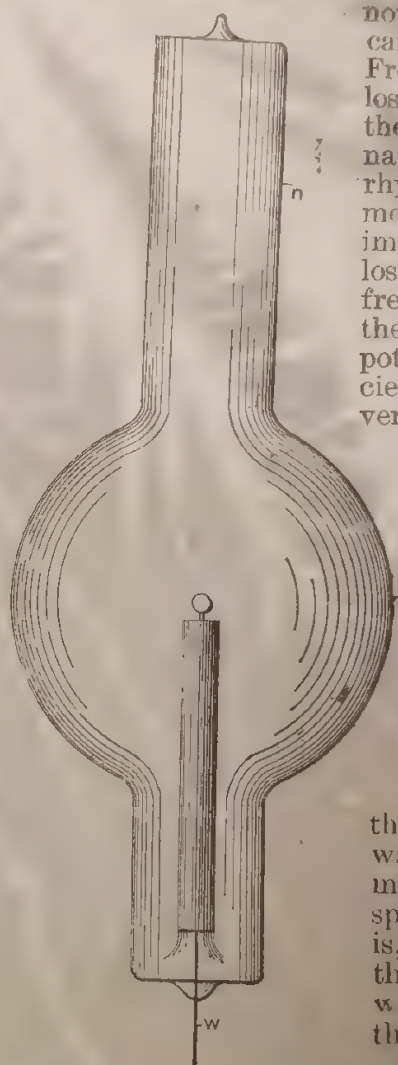


FIG. 25.—IMPROVED EXPERIMENTAL BULB.

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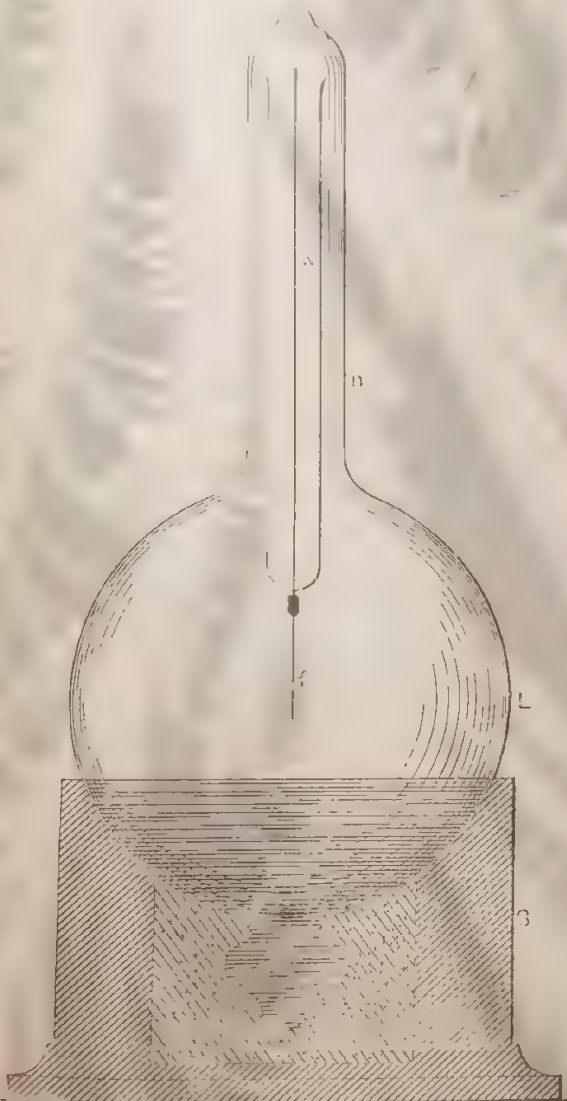


FIG. 24.—BULB WITHOUT LEADING-IN WIRE, SHOWING EFFECT OF PROJECTED MATTER.

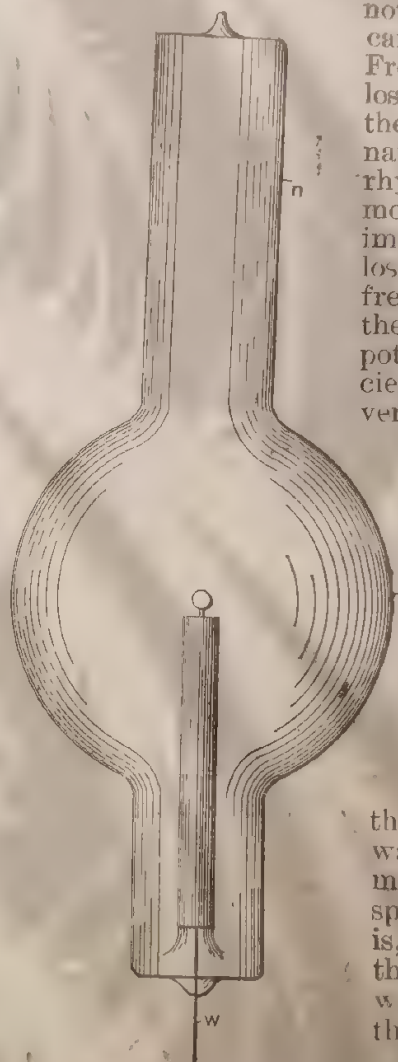


FIG. 25.—IMPROVED EXPERIMENTAL BULB.

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the farther ones. When the nearest molecule within the inductive action of the sphere. It that, if the potential be steady, but little loss of be caused in this way, for the molecules which to the sphere, having had an additional charge them by contact, are not attracted until they ha not with all, at least with most of the additional c can be accomplished only after a great mar From the fact that with a steady potential ther loss in dry air, one must come to such a conclu the potential of the sphere, instead of being sta nating, the conditions are entirely different. rhythmic bombardment occurs, no matter molecules after coming in contact with the sp imparted charge or not; what is more, if the lost, the impacts are only the more violent frequency of the impulses be very small, the l the impacts and collisions would not be serio potential were excessive. But when extremely, cies and more or less high potentials are used, th very great. The total energy lost per unit of ti tionate to the product of the number o second, or the frequency and the energy impact. But the energy of an impact m tionate to the square of the electric c sphere, since the charge imparted to th proportionate to that density. I conclude the total energy lost must be proportiona duct of the frequency and the square c density: but this law needs experimental Assuming the preceding considerations to b rapidly alternating the potential of a b in an insulating gaseous medium, any am may be dissipated into space. Most of then, I believe, is not dissipated in the form waves, propagated to considerable distance, most generally, but is consumed—in the case sphere, for example—in impact and collision is, heat vibrations—on the surface and in the sphere. To reduce the dissipation it is work with a small electric density—the sma the frequency.

But since, on the assumption before ma diminished with the square of the density, rents of very high frequencies involve con when transmitted through conductors, it the whole, it is better to employ one Therefore, if motors, lamps, or devices c perfected, capable of being advantageous the farther ones. When the nearest molecule sphere they are repelled, and collisions occur at within the inductive action of the sphere. It that, if the potential be steady, but little loss of be caused in this way, for the molecules which to the sphere, having had an additional charge them by contact, are not attracted until they ha not with all, at least with most of the additional c can be accomplished only after a great mar From the fact that with a steady potential ther loss in dry air, one must come to such a conclu the potential of the sphere, instead of being sta nating, the conditions are entirely different. rhythmic bombardment occurs, no matter molecules after coming in contact with the sp imparted charge or not; what is more, if the lost, the impacts are only the more violent frequency of the impulses be very small, the l the impacts and collisions would not be serio potential were excessive. But when extremely, cies and more or less high potentials are used, th very great. The total energy lost per unit of ti tionate to the product of the number o second, or the frequency and the energy impact. But the energy of an impact m tionate to the square of the electric c sphere, since the charge imparted to th proportionate to that density. I conclude the total energy lost must be proportiona duct of the frequency and the square c density: but this law needs experimental Assuming the preceding considerations to b rapidly alternating the potential of a b in an insulating gaseous medium, any am may be dissipated into space. Most of then, I believe, is not dissipated in the form waves, propagated to considerable distance, most generally, but is consumed—in the case sphere, for example—in impact and collision is, heat vibrations—on the surface and in the sphere. To reduce the dissipation it is work with a small electric density—the sma the frequency.

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but there are upon it points constantly shifting and wandering around, of a temperature far above the mean, and this materially hastens the process of deterioration. That some such thing occurs, at least when the electrode is at a lower temperature, sufficient experimental evidence can be obtained in the following manner: Exhaust a bulb to a very high degree, so that with a fairly high potential the discharge cannot pass—that is, not a *luminous* one, for a weak invisible discharge occurs always, in all probability. Now raise slowly and carefully the potential, leaving the primary current on no more than for an instant. At a certain point, two, three, or half a dozen phosphorescent spots will appear on the globe. These places of the glass are evidently more violently bombarded than others, this being due to the unevenly distributed electric density, necessitated, of course, by sharp projections, or, generally speaking, ir-

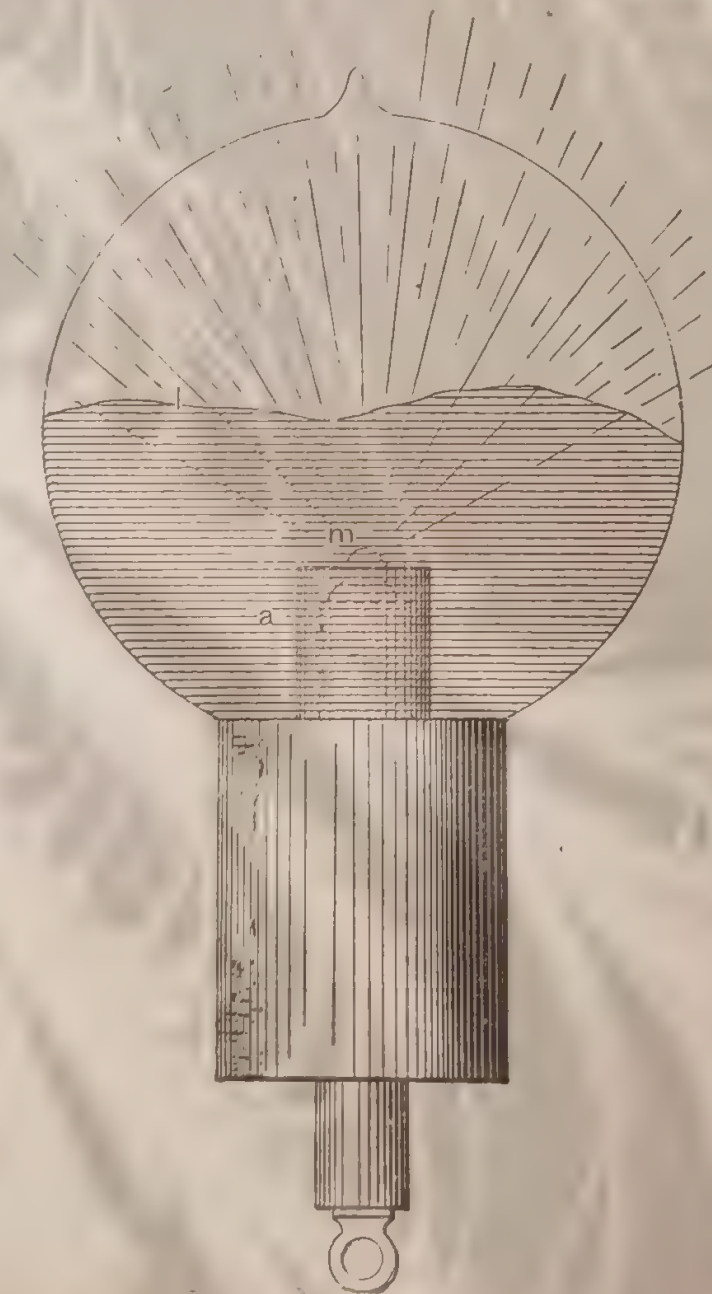


FIG. 23.—EFFECT PRODUCED BY A RUBY DROP.

regularities of the electrode. But the luminous patches are constantly changing in position, which is especially well observable if one manages to produce very few, and this indicates that the configuration of the electrode is rapidly changing.

From experiences of this kind I am led to infer that, in order to be most durable, the refractory button in the bulb should be in the form of a sphere with a highly polished surface. Such a small sphere could be manufactured from a diamond or some other crystal, but a bet-

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slipped on the stem, the pressure prevent it from slipping off, but, of the sheet may be turned in—corner of the sheet—that is, the refractory incandescent body gonally, as it often happens of the intense heat, this inside and comes very near wire, or filament, supporting the er part of the energy supplied to heating the metal tube, and the the purpose. The aluminium he glass stem more or less—one ass be too close to the incandes- ly heated and become more or it may be ruptured, or may, by good electrical connection be- e leading-in wire, in which case, ill be lost in heating the former. make the top of the glass tube, h smaller diameter. To still arising from the heating of the e view of preventing an electri- metal tube and the electrode, I th several layers of thin mica, as the metal tube. In some tside insulating cover. e only made to aid the experi- the difficulties which he en- means to overcome in his own

he screen, and the advantage bulbs of the same size, with and incandescent lamp fila- nearly alike as possible. The with an aluminium tube, the Originally the two bulbs were connected to a Sprengel pump. en reached, first the connect- lbs, were sealed off; they are of exhaustion. When they he coil giving a certain poten- the bulb provided with the d highly incandescent, while lb may, with the same po- redness, although in reality rally more energy than the e both connected together lference is even more ance of the screening. The m containing the leading-in ject functions: First: it acts ic screen, thus economizing lb; and, second, to whatever rostatically, it acts mechan- dment, and consequently in- terioration of the slender sup- escent body, or of the glass n wire. I say slender sup- rder to confine the heat more g body its support should be the smallest possible amount l the supports used I have ent lamp filament to be the ng conductors it can with- eat.

metal tube as an electrostatic degree of exhaustion. es of exhaustion—which are d special means in connection n the matter in the globe is most perfectly. The shadow e then sharply defined as

insulator; secondly, which first come in contact with it, the progress of the fol- lowing atoms against the tube is more or less checked by the repulsion which the electrified tube must exert upon the similarly electrified atoms. This repulsion may per- haps be sufficient to prevent a large portion of the atoms from striking the tube, but at any rate it must diminish the energy of their impact. It is clear that when the exhaust- tion is very low, and the rarefied gas well conducting, neither of the above effects can occur, and, on the other hand, the fewer the atoms, with the greater freedom they move; in other words, the higher the degree of exhaustion, up to a limit, the more telling will be both the effects.

What I have just said may afford an explanation of the phenomenon observed by Prof. Crookes, namely, that a discharge through a bulb is established with much greater facility when an insulator than when a conductor is pres- ent in the same. In my opinion, the conductor acts as a dampener of the motion of the atoms in the two ways pointed out; hence, to cause a visible discharge to pass through the bulb, a much higher potential is needed if a conductor, especially of much surface, be present.

For the sake of clearness of some of the remarks before made, I must now refer to Figs. 18, 19 and 20, which illus- trate various arrangements with a type of bulb most gen- erally used.

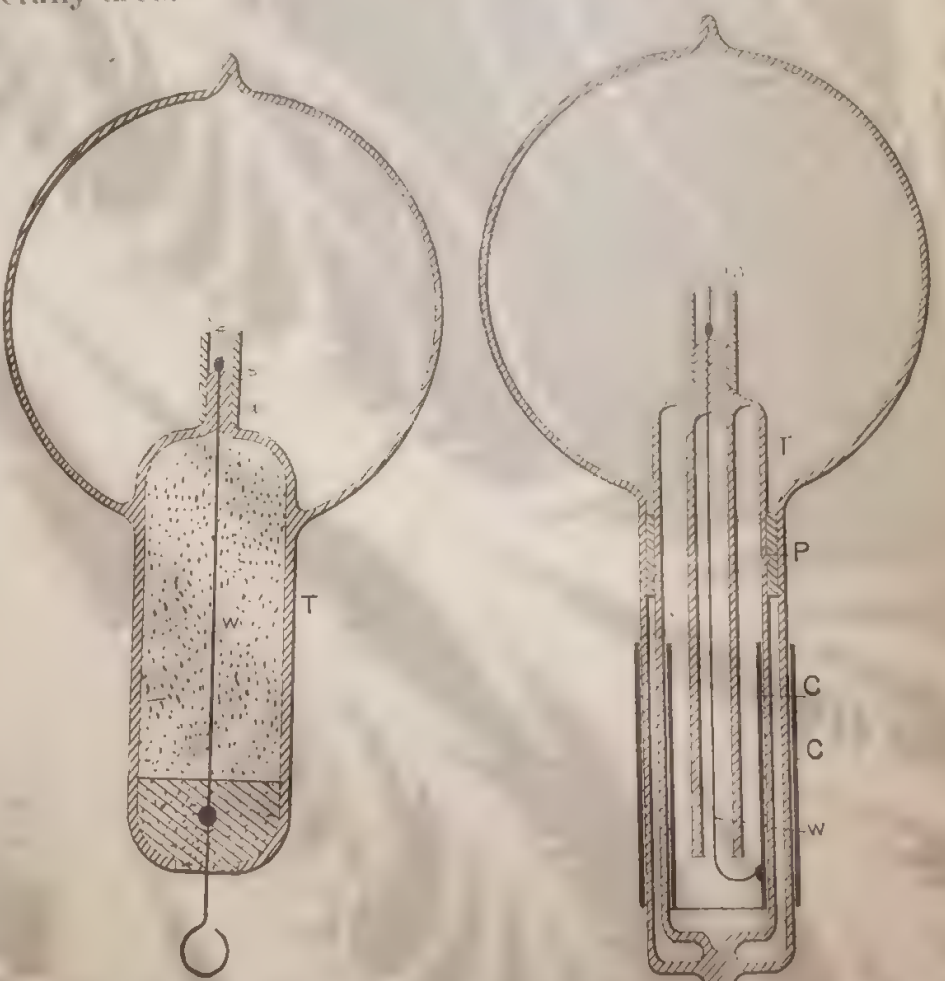


FIG. 21.—IMPROVED BULB WITH NON-CONDUCTING BUTTON. FIG. 22.—TYPE OF BULB WITHOUT LEADING-IN WIRE.

Fig. 18 is a section through a spherical bulb *L*, with the glass stem *s*, containing the leading-in wire *w*, which has a lamp filament *l* fastened to it, serving to support the refractory button *m* in the centre. *M* is a sheet of thin mica wound in several layers around the stem *s*, and *a* is the aluminium tube.

Fig. 19 illustrates such a bulb in a somewhat more ad- vanced stage of perfection. A metallic tube *S* is fastened by means of some cement to the neck of the tube. In the tube is screwed a plug *P*, of insulating material, in the centre of which is fastened a metallic terminal *t*, for the connection to the leading-in wire *w*. This terminal must be well insulated from the metal tube *S*, therefore, if the cement used is conducting—and most generally it is suf- ficiently so—the space between the plug *P* and the neck of the bulb should be filled with some good insulating ma- terial, as mica powder.

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seems beyond doubt that the best among
employ for this purpose is aluminium, on account of
its many remarkable properties. Its only fault is that
it is easily fusible, and, therefore, its distance from the
incandescing body should be properly estimated. Usually,
a thin tube, of a diameter somewhat smaller than that of
the glass stem, is made of the finest aluminium sheet, and
slipped on the stem. The tube is conveniently prepared by
wrapping around a rod fastened in a lathe a piece of alu-
minium sheet of the proper size, grasping the sheet firmly
with clean chamois leather or blotting paper, and spinning
the rod very fast. The sheet is wound tightly around the
rod, and a highly polished tube of one or three layers of the

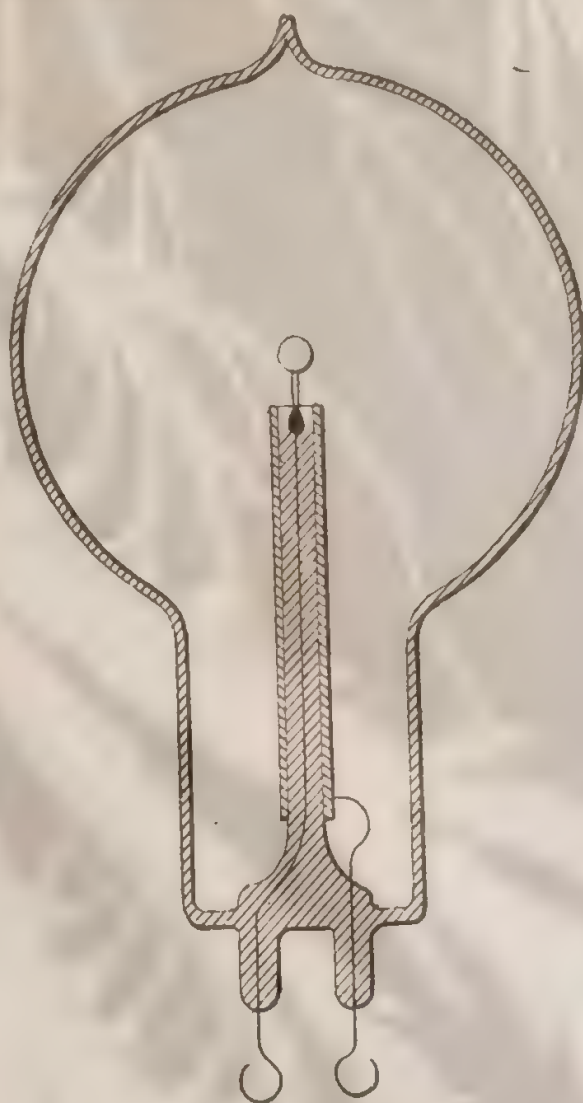


FIG. 20.—BULB FOR EXPERIMENTS WITH CONDUCTING TUBE.

sheet is obtained. When slipped on the stem, the pressure
is generally sufficient to prevent it from slipping off, but,
for safety, the lower edge of the sheet may be turned in-
side. The upper inside corner of the sheet—that is, the
one which is nearest to the refractory incandescent body
—should be cut out diagonally, as it often happens
that, in consequence of the intense heat, this
corner turns toward the inside and comes very near
to, or in contact with, the wire, or filament, supporting the
refractory body. The greater part of the energy supplied to
the bulb is then used up in heating the metal tube, and the
bulb is rendered useless for the purpose. The aluminium
sheet should project above the glass stem more or less—one
inch or so—or else, if the glass be too close to the incandes-
cing body, it may be strongly heated and become more or

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This object is best attained in the spherical bulb; but it is also attained in a cylindrical vessel with one or two straight filaments coinciding with its axis, and possibly also in parabolical or spherical bulbs with the refractory body or bodies placed in the focus or foci of the same; though the latter is not probable, as the electrified atoms should in all cases rebound normally from the surface they strike, unless the speed were excessive, in which case they *would* probably follow the general law of reflection. No matter what shape the vessel may have, if the exhaustion be low, a filament mounted in the globe is brought to the same degree of incandescence in all parts; but if the exhaustion be high and the bulb be spherical or pear-shaped, as usual, focal points form and the filament is heated to a higher degree at or near such points.

To illustrate the effect, I have here two small bulbs which are alike, only one is exhausted to a low and the other to a very high degree. When connected to the coil, the fila-

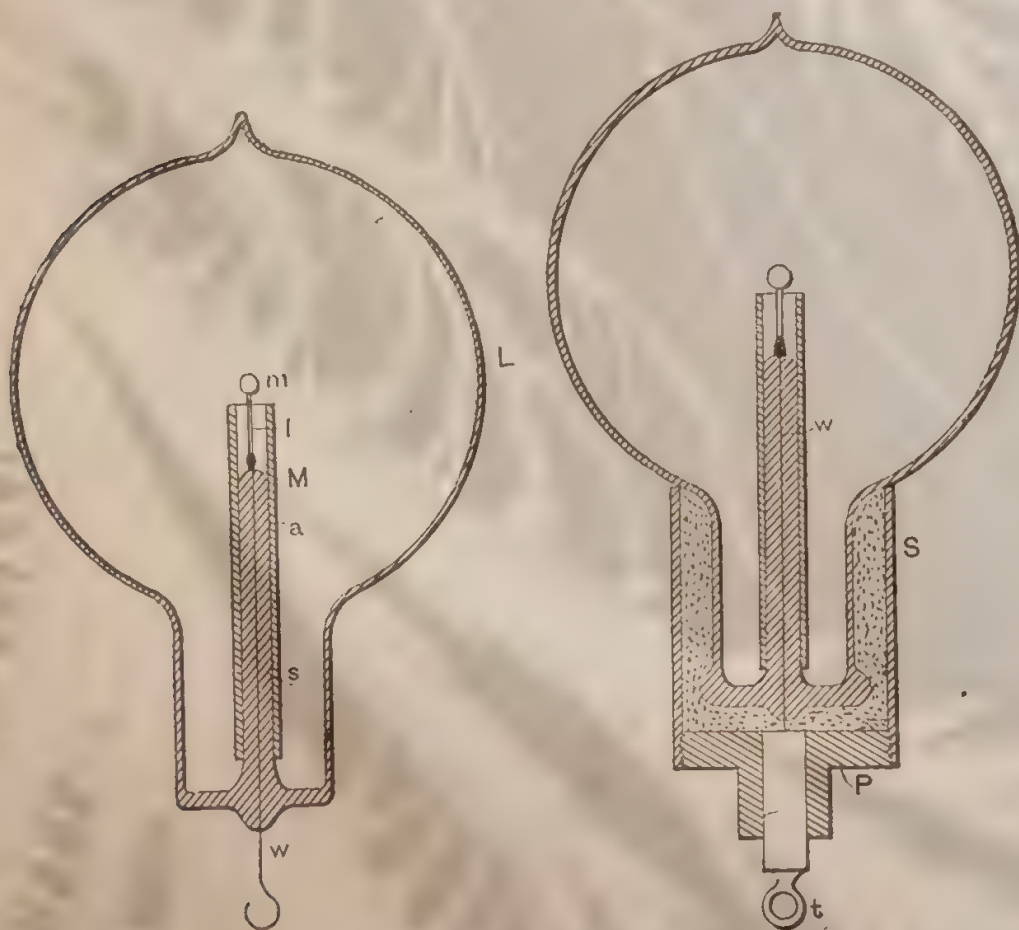


FIG. 18.—BULB WITH MICA TUBE AND ALUMINIUM SCREEN.

FIG. 19.—IMPROVED BULB WITH SOCKET AND SCREEN.

ment in the former glows uniformly throughout all its length; whereas in the latter, that portion of the filament which is in the centre of the bulb glows far more intensely than the rest. A curious point is that the phenomenon occurs even if two filaments are mounted in a bulb, each being connected to one terminal of the coil, and, what is still more curious, if they be very near together, provided the vacuum be very high. I noted in experiments with such bulbs that the filaments would give way usually at a certain point, and in the first trials I attributed it to a defect in the carbon. But when the phenomenon occurred many times in succession I recognized its real cause.

In order to bring a refractory body inclosed in a bulb to incandescence, it is desirable, on account of economy, that all the energy supplied to the bulb from the source should reach without loss the body to be heated; from there, and from nowhere else, it should be radiated. It is, of course, out of the question to reach this theoretical result, but it is possible by a proper construction of the illuminating device to approximate it more or less.

For many reasons, the refractory body is placed in the centre of the bulb, and it is usually supported on a glass

—should be the case that, in consequence of that, in consequence of corner turns toward the inside, or in contact with, the wire, refractory body. The greater part of the bulb is then used up in heating the bulb is rendered useless for the sheet should project above the glass inch or so—or else, if the glass heating body, it may be strongly less conducting, whereupon it may its conductivity, establish a good between the metal tube and the lead again, most of the energy will be. Perhaps the best way is to make for about an inch, of a much smaller further reduce the danger arising glass stem, and also with the visual connection between the metal preferably wrap the stem with a which extends at least as far as the bulbs I have also used an outside

The preceding remarks are only a pointer in the first trials, for the counters he may soon find many a way.

To illustrate the effect of the use of using it, I have here two bulbs of their stems, leading-in wires and elements tied to the latter, as near the stem of one bulb is provided with stem of the other has none. Or joined by a tube which was common. When a high vacuum had been in the tube, and then the bulbs, therefore of the same degree of exhaustion are separately connected to the terminal, the carbon filament in the aluminium screen is rendered incandescent, the filament in the other bulb does not even come to red heat, the latter bulb takes general form. When they are connected to the terminal, the difference is apparent, showing the importance of the metal tube placed on the stem, the wire performs really two distinct functions, more or less as an electrostatic shield, the energy supplied to the bulb to the extent it may fail to act electrostatically, preventing the bombardment, intense heating and possible deterioration of the refractory incandescent stem containing the leading-in wires, for it is evident that in order to be completely to the incandescing, very thin, so as to carry away the heat of heat by conduction. Of all the found an ordinary incandescent best, principally because among them stand the highest degrees of heat.

The effectiveness of the metal screen depends largely on the degree of exhaustion.

At excessively high degrees of heat reached by using great care and with the Sprengel pump—when in the ultra-radiant state, it acts as a shield, the upper edge of the tube is the bulb.

At a somewhat lower degree of exhaustion the ordinary "non-striking" bulb

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means of a single coil and core; my explanation of the phenomenon, and leading thought in trying the experiment, being that there must be a true time lag in the magnetization of the core. I remember the pleasure I had when, in the writings of Professor Ayrton, which came later to my hand, I found the idea of the time lag advocated. Whether there is a true time lag, or whether the retardation is due to eddy currents circulating in minute paths, must remain an open question, but the fact is that a coil wound upon an iron core and traversed by an alternating

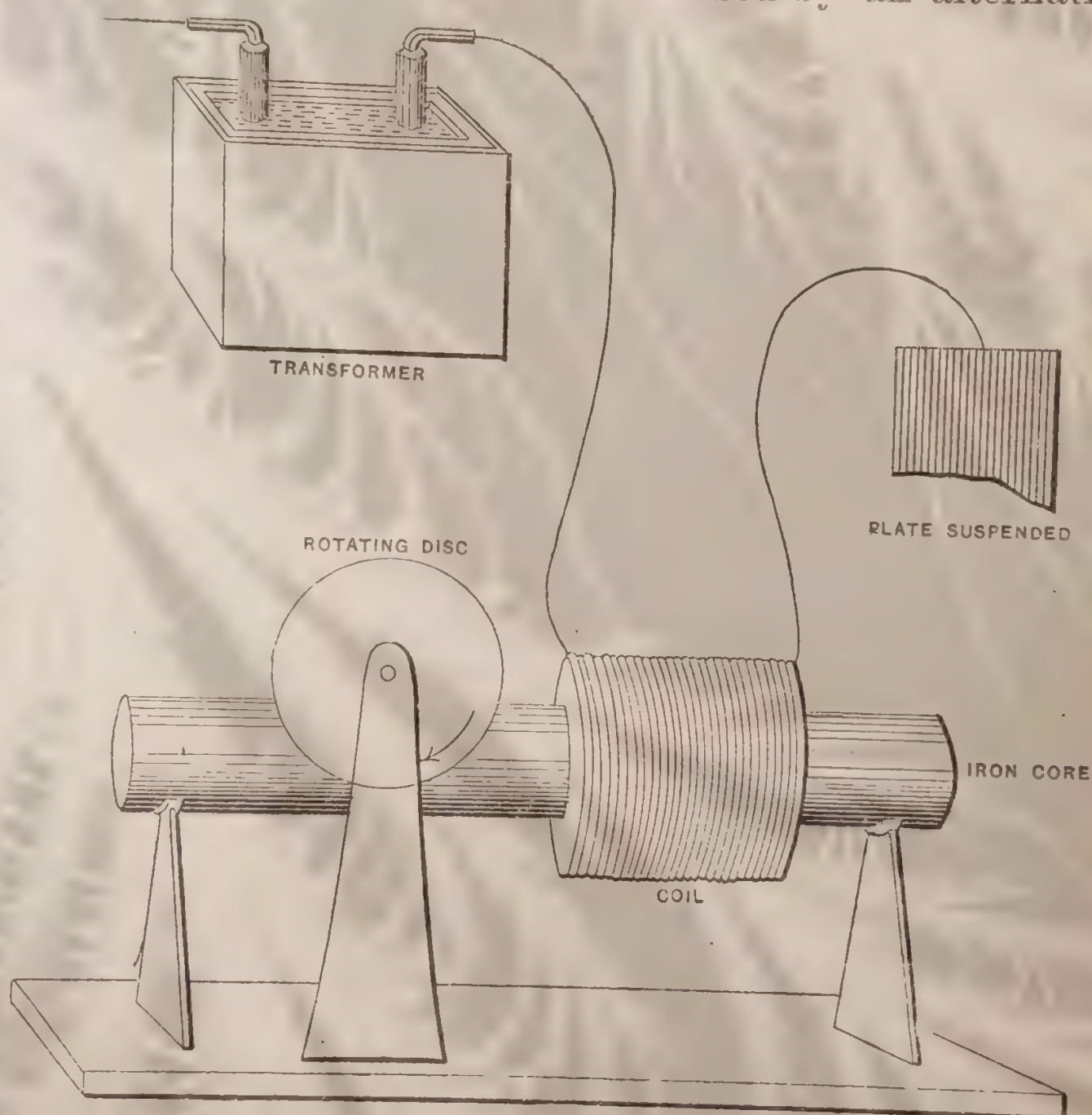


FIG. 17.—SINGLE WIRE AND "NO-WIRE" MOTOR.

current creates a moving field of force, capable of setting an armature in rotation. It is of some interest, in conjunction with the historical Arago experiment, to mention that in lag or phase motors I have produced rotation in the opposite direction to the moving field, which means that in that experiment the magnet may not rotate, or may even rotate in the opposite direction to the moving disc. Here, then, is a motor (diagrammatically illustrated in Fig. 17), comprising a coil and iron core, and a freely movable copper disc in proximity to the latter.

To demonstrate a novel and interesting feature, I have, for a reason which I will explain, selected this type of

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means of a single coil and core; my explanation of the phenomenon, and leading thought in trying the experiment, being that there must be a true time lag in the magnetization of the core. I remember the pleasure I had when, in the writings of Professor Ayrton, which came later to my hand, I found the idea of the time lag advocated. Whether there is a true time lag, or whether the retardation is due to eddy currents circulating in minute paths, must remain an open question, but the fact is that a coil wound upon an iron core and traversed by an alternating

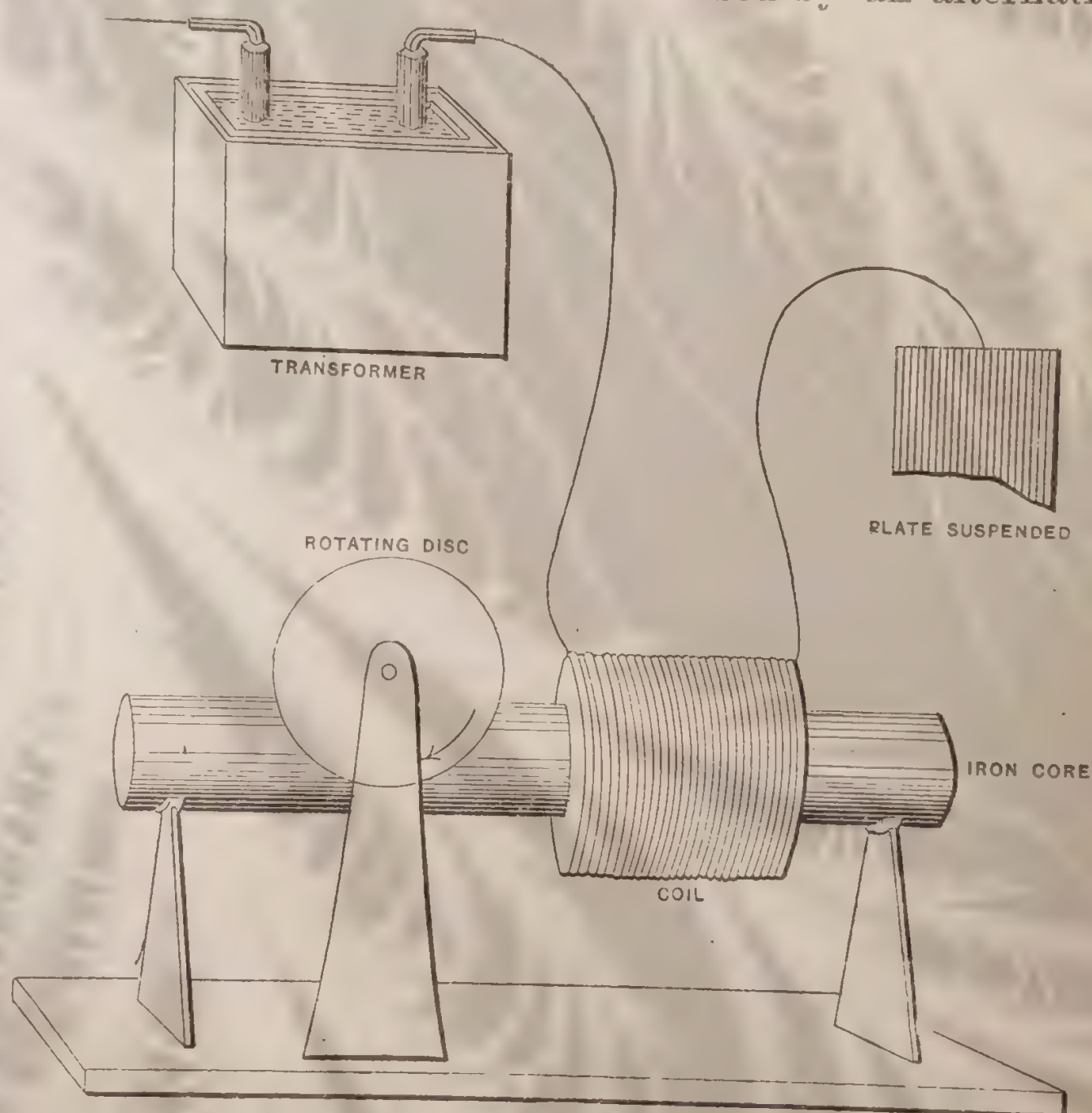


FIG. 17.—SINGLE WIRE AND "NO-WIRE" MOTOR.

current creates a moving field of force, capable of setting an armature in rotation. It is of some interest, in conjunction with the historical Arago experiment, to mention that in lag or phase motors I have produced rotation in the opposite direction to the moving field, which means that in that experiment the magnet may not rotate, or may even rotate in the opposite direction to the moving disc. Here, then, is a motor (diagrammatically illustrated in Fig. 17), comprising a coil and iron core, and a freely movable copper disc in proximity to the latter.

To demonstrate a novel and interesting feature, I have, for a reason which I will explain, selected this type of

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small sphere *s*, sealed to it, so that two entirely independent compartments are formed, as indicated in the drawing. When the bulb is in use, the neck *n* is provided with a tin-foil coating, which is connected to the generator and acts inductively upon the moderately rarefied and highly conducting gas inclosed in the neck. From there the current passes through the tube *b* into the small sphere *s*, to act by induction upon the gas contained in the globe *L*.

It is of advantage to make the tube *t* very thick, the hole through it very small, and to blow the sphere *s* very thin. It is of the greatest importance that the sphere *s* be placed in the centre of the globe *L*.

Figs. 14, 15 and 16 indicate different forms, or stages, of

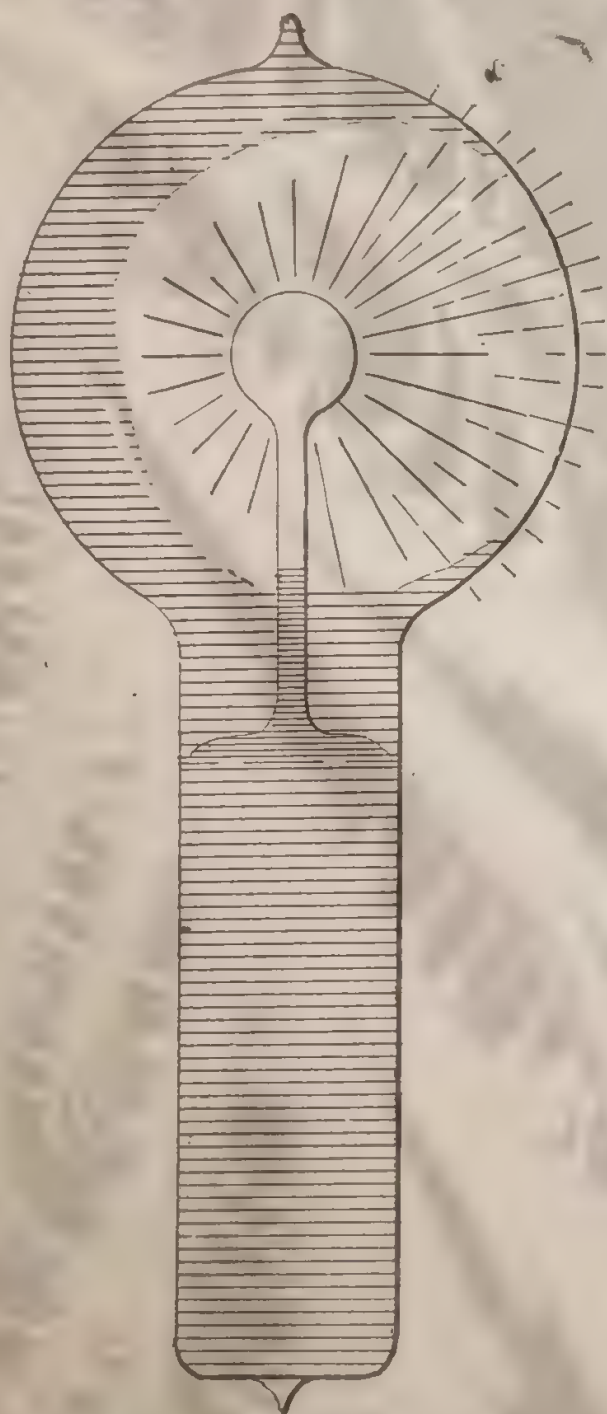


FIG. 15.

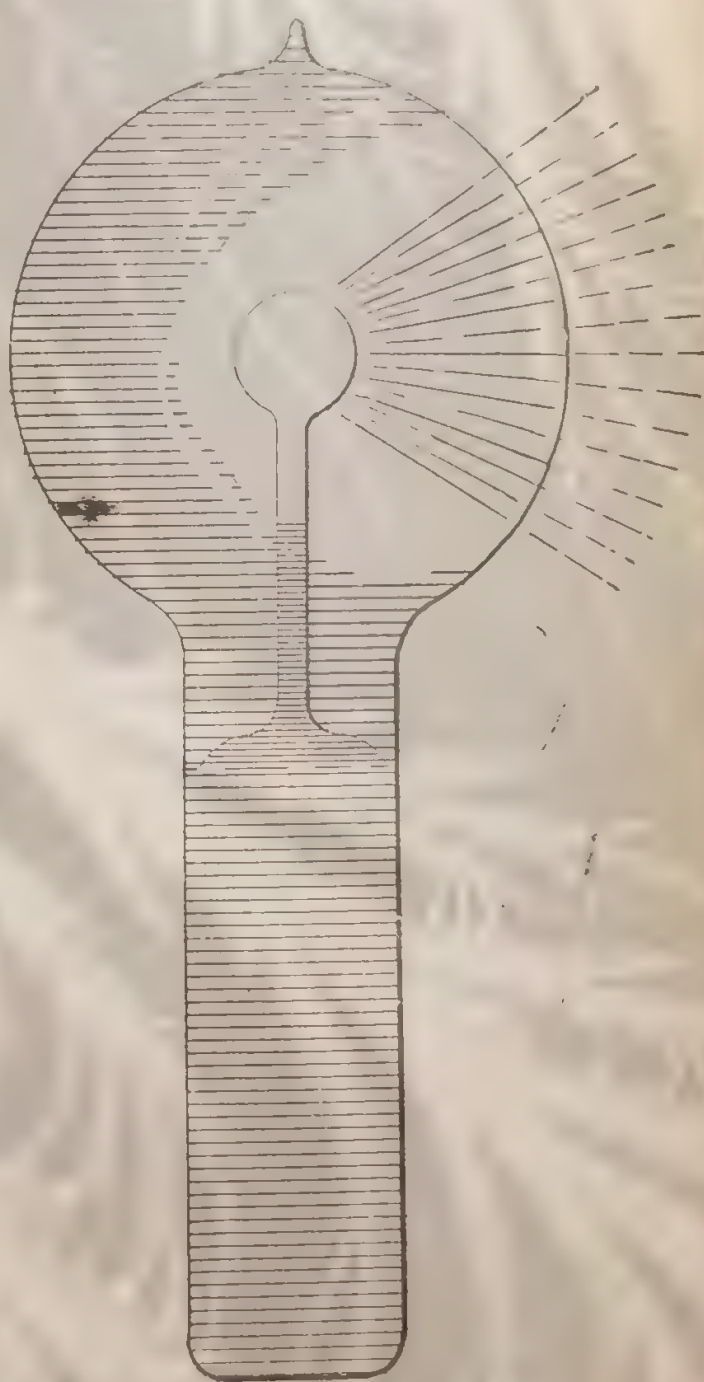


FIG. 16.

FORMS AND PHASES OF THE ROTATING BRUSH.

the brush. Fig. 14 shows the brush as it first appears in a bulb provided with a conducting terminal; but, as in such a bulb it very soon disappears—often after a few minutes—I will confine myself to the description of the phenomenon as seen in a bulb without conducting electrode. It is observed under the following conditions:

When the globe *L* (Figs. 12 and 13) is exhausted to a very high degree, generally the bulb is not excited upon

small sphere *s*, sealed to it, so that two entirely independent compartments are formed, as indicated in the drawing. When the bulb is in use, the neck *n* is provided with a tin-foil coating, which is connected to the generator and acts inductively upon the moderately rarefied and highly conducting gas inclosed in the neck. From there the current passes through the tube *b* into the small sphere *s*, to act by induction upon the gas contained in the globe *L*.

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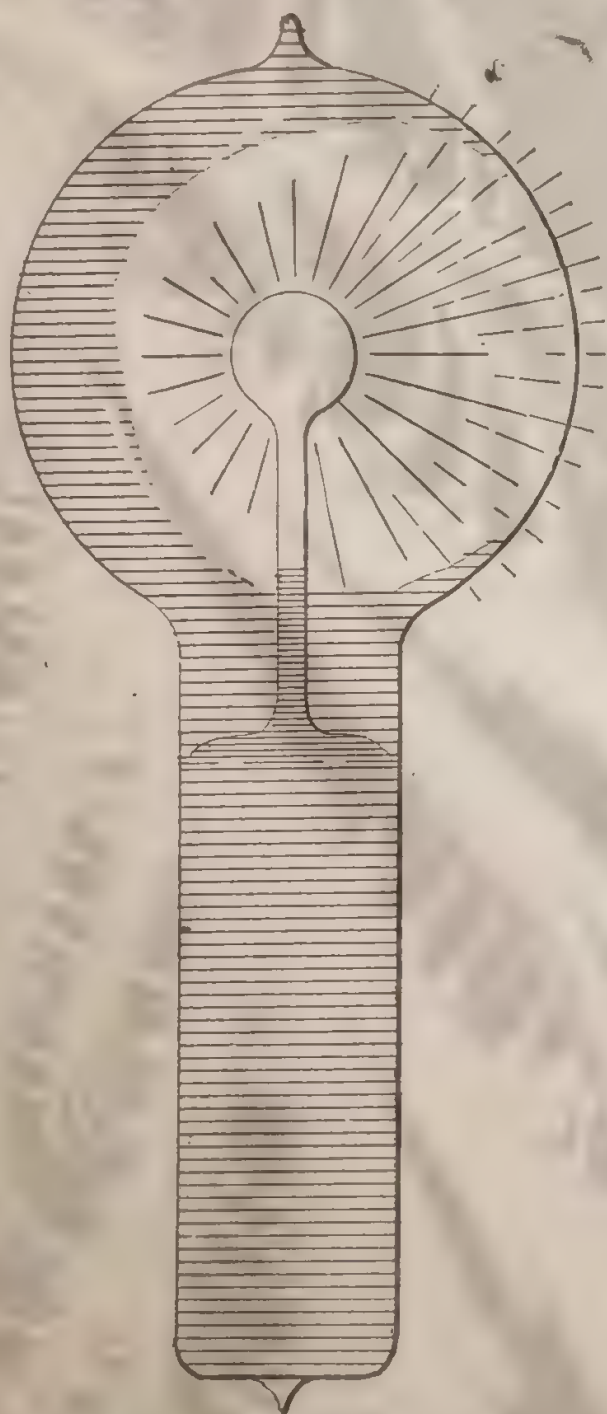


FIG. 15.

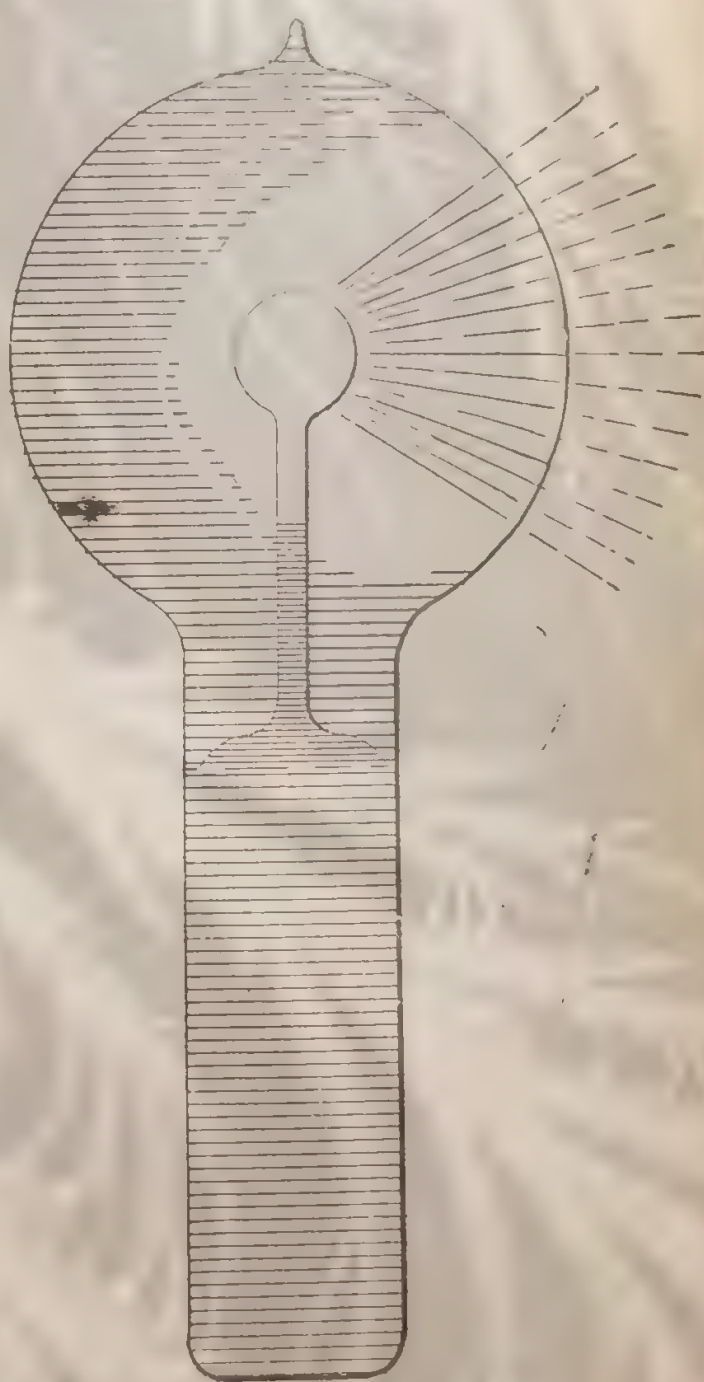


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The first thing, then, in operating the induction coil is to combine capacity with the secondary to overcome the self-induction. If the frequencies and potentials are very high gaseous matter should be carefully kept away from the charged surfaces. If Leyden jars are used, they should be immersed in oil, as otherwise considerable dissipation may occur if the jars are greatly strained. When high

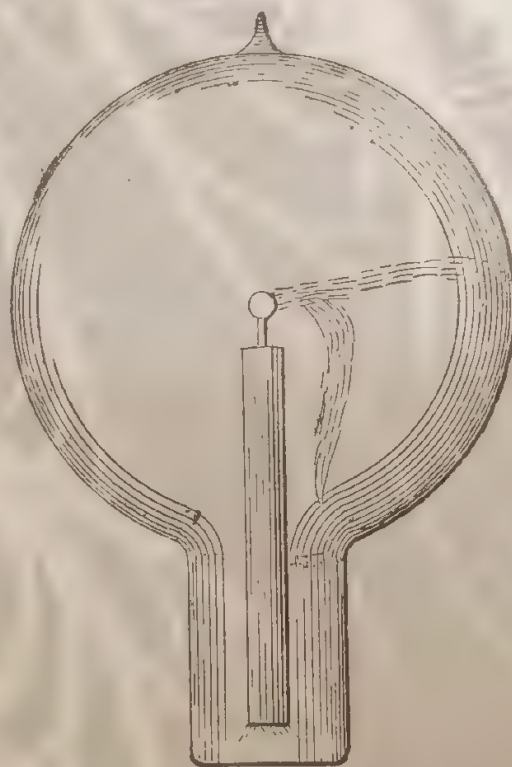


FIG. 14.—FORMS AND PHASES OF THE ROTATING BRUSH.

frequencies are used, it is of equal importance to combine a condenser with the primary. One may use a condenser connected to the ends of the primary or to the terminals of the alternator, but the latter is not to be recommended, as the machine might be injured. The best way is undoubt-

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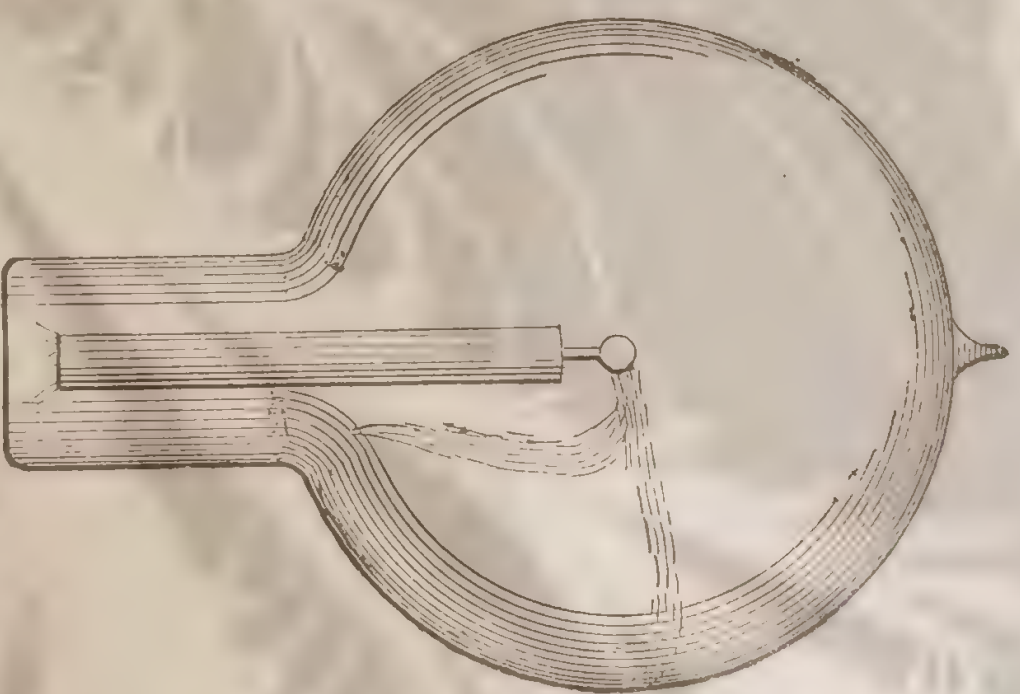


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to cite it, it is usually successful. An intense phenomenon. Shortly afterward on evenly distributed in rent for some time through this stage the phenomenon indicated in Fig. 16, a few weeks, according to the bulb or increasing the brush as it may be brought to electrostatic and magnetic straight down from it, the approach of the bulb will cause and if he walks around opposite side. It may long before it reaches to turn around principle a magnet, and at a magnetic influence to a permanent magnet, with two centimetres, with metres, slowing down ing to how it is he have observed that magnetic, it is not magnetic. My explanation is, the brush and the station, grows much when the intensity. When the bulb is always clock would occur in the the brush should not reversed by a magnet

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a vacuum pump, and the other with a vessel containing a sufficient quantity of boiled-out oil. The latter tube has a very small hole at the bottom, and is provided with a stop-cock. When a fairly good vacuum has been obtained, the stopcock is opened and the oil slowly fed in. Proceeding in this manner, it is impossible that any big bubbles, which are the principal danger, should remain between the turns. The air is most completely excluded, probably better than by boiling out, which, however, when gutta-percha coated wires are used, is not practicable.

For the primaries I use ordinary line wire with a thick cotton coating. Strands of very thin insulated wires

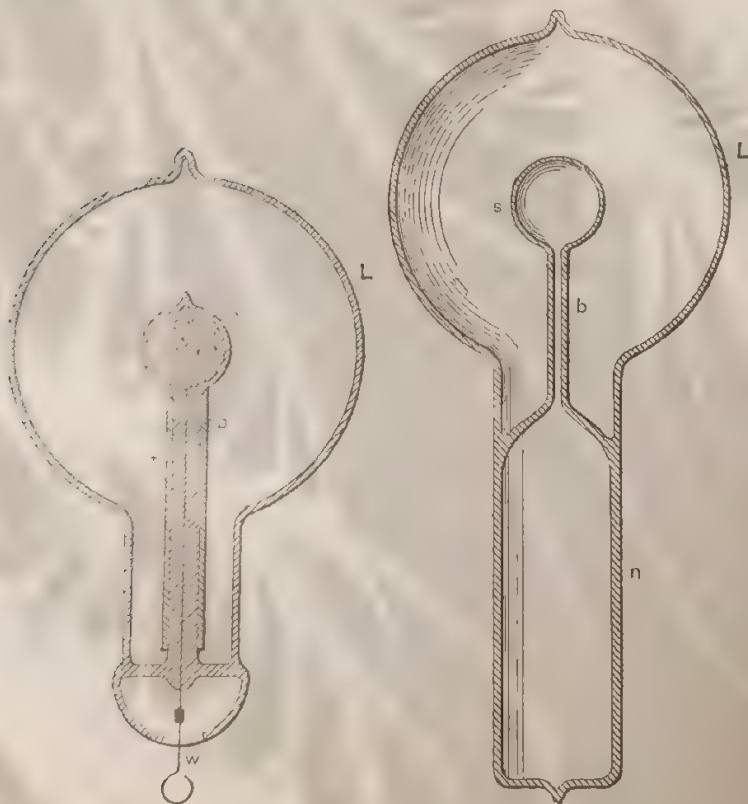


FIG. 12.

FIG. 13.

BULBS FOR PRODUCING ROTATING BRUSH.

properly interlaced would, of course, be the best to employ for the primaries, but they are not to be had.

In an experimental coil the size of the wires is not of great importance. In the coil here used the primary is No. 12 and the secondary No. 24 Brown & Sharpe gauge wire; but the sections may be varied considerably. It would only be a vacuum pump, and the other with a vessel containing a sufficient quantity of boiled-out oil. The latter tube has a very small hole at the bottom, and is provided with a stop-cock. When a fairly good vacuum has been obtained, the stopcock is opened and the oil slowly fed in. Proceeding in this manner, it is impossible that any big bubbles, which are the principal danger, should remain between the turns. The air is most completely excluded, probably better than by boiling out, which, however, when gutta-percha coated wires are used, is not practicable.

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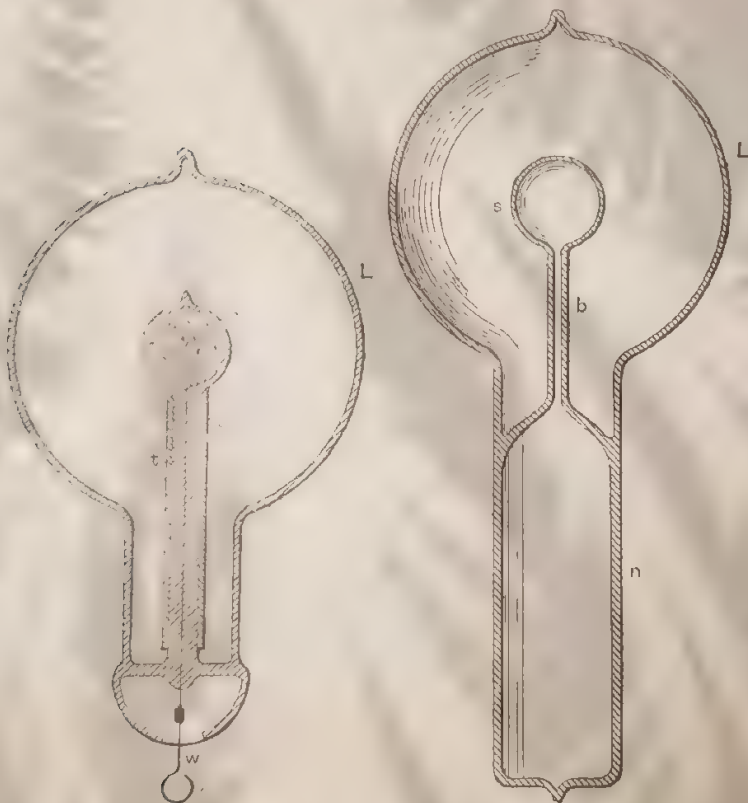


FIG. 12.

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In most of the succeeding experiments I prefer, on account of the regular and positive action, to the alternator before referred to. This is one of the several machines constructed by me for the purposes of investigations. It has 384 pole projections, and is of giving currents of a frequency of about 10,000 per second. This machine has been illustrated and described in my first paper before the American Institute of Electrical Engineers, May 20, 1891, to which I have referred. A more detailed description, sufficient to any engineer to build a similar machine, will be found in several electrical journals of that period.

The induction coils operated from the machine are small, containing from 5,000 to 15,000 turns in the primary. They are immersed in boiled-out linseed oil contained in wooden boxes covered with zinc sheet.

I have found it advantageous to reverse the position of the wires, and to wind, in these coils, the primary on the top; this allowing the use of a much bigger primary, which, of course, reduces the danger of overheating and increases the output of the coil. I make the primary on each side at least one centimetre shorter than the secondary to prevent the breaking through on the ends, which surely occur unless the insulation on the top of the primary be very thick, and this, of course, would be disadvantageous.

When the primary is made movable, which is not in some experiments, and many times convenient for purposes of adjustment, I cover the secondary with a thin sheet of metal and turn it off in a lathe to a diameter slightly smaller than the inside of the primary coil. The latter I turn with a handle reaching out of the oil, which serves to move it in any position along the secondary.

I will now venture to make, in regard to the manipulation of induction coils, a few observations upon points which have not been fully appreciated in earlier experiments with such coils, and are even overlooked.

The secondary of the coil possesses usually sufficient self-induction that the current through the wire is appreciable, and may be so even when the terminals are joined by a conductor of small resistance. If a small resistance is added to the terminals, the self-induction is counteracted, and a stronger current is made to flow through the primary, though its terminals are insulated from the secondary. To one entirely unacquainted with the properties of inducting currents nothing will look more puzzling than the feature was illustrated in the experiment performed beginning with the top plates of wire gauze attached to the terminals and the rubber plate. When the plates of wire gauze were close together, and a small arc passed between them, the arc prevented a strong current from flowing through the secondary, because it did away with the self-induction.

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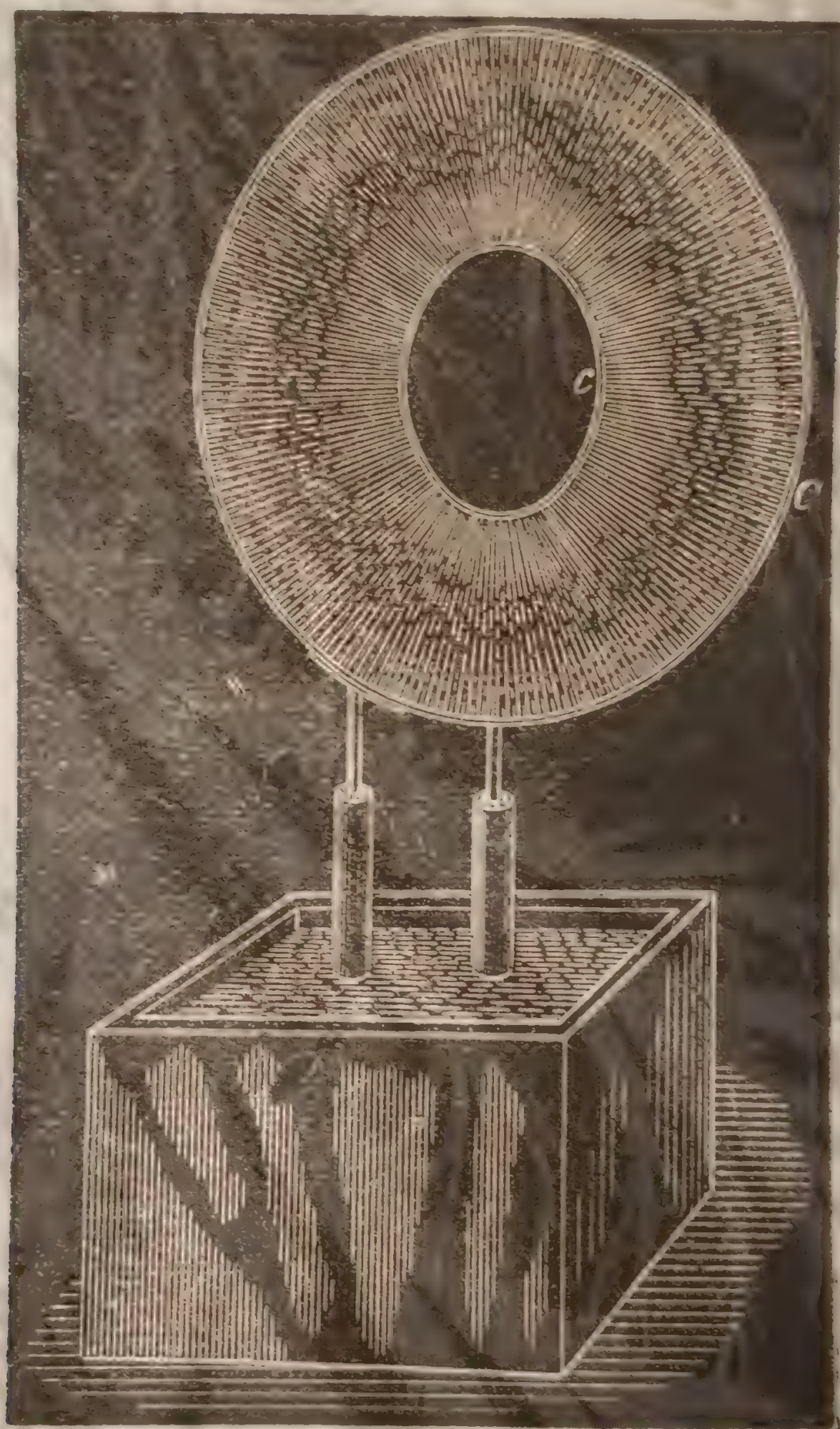


FIG. 10.—LUMINOUS DISCS.

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spheres—or, better still, two sharp-edged metal discs (*d d*, Fig. 11) of no more than a few centimetres in diameter—

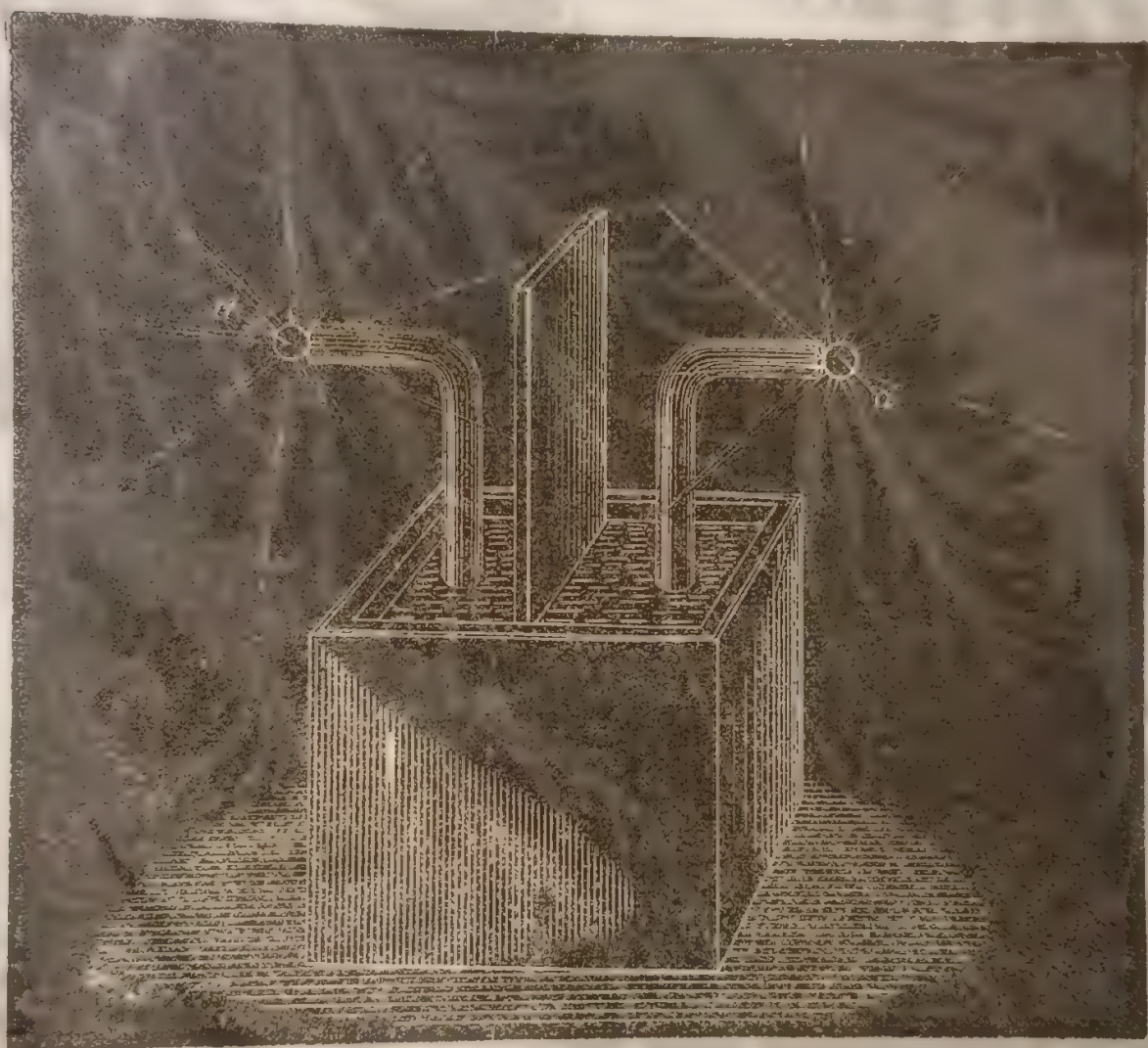


FIG. 11.—PHANTOM STREAMS.

should be exposed to the air. The coil here used is immersed in oil, and the ends of the secondary reaching out of the

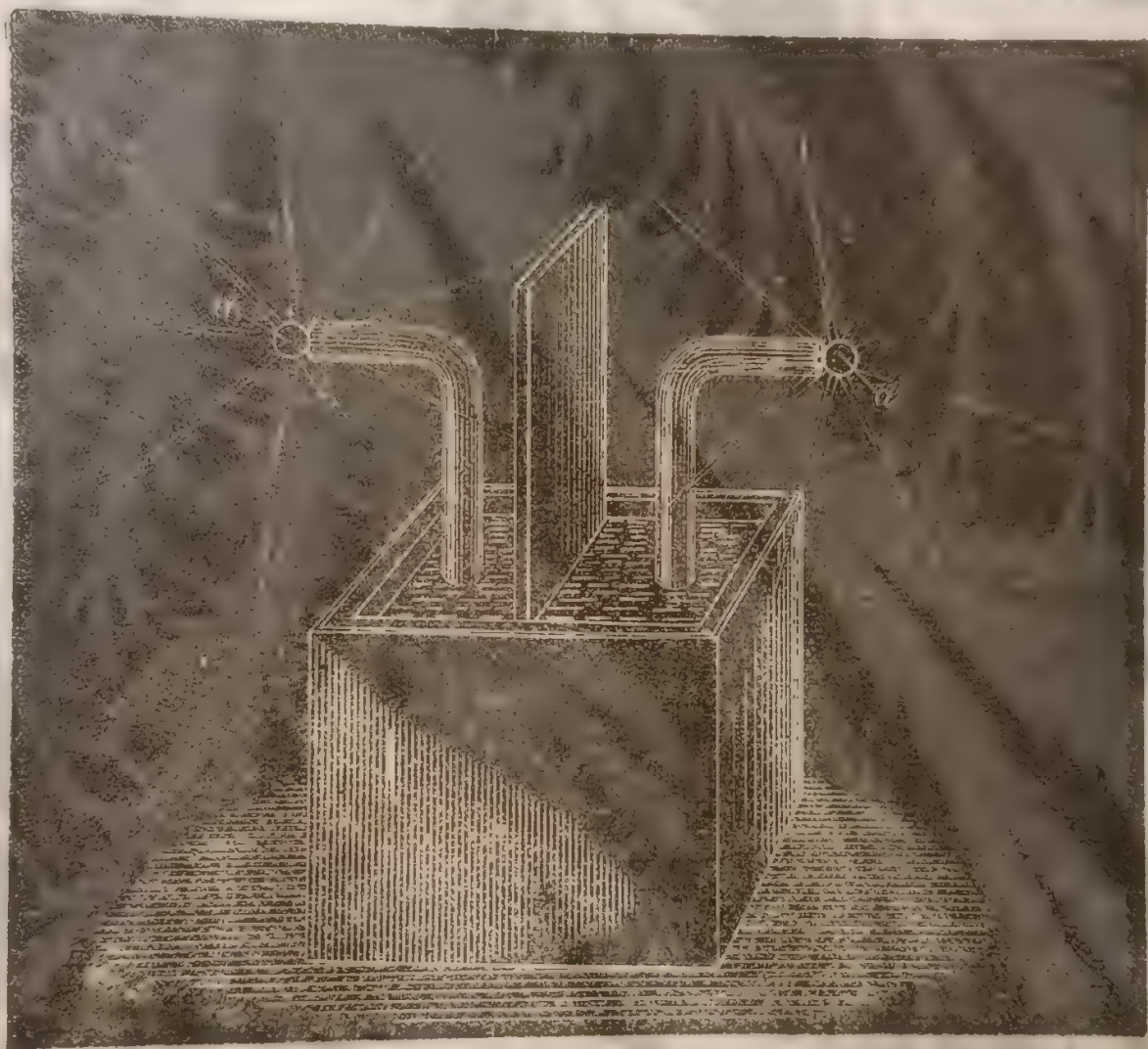


FIG. 11.—PHANTOM STREAMS.

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experiment. In trials of this kind the experimenter arrives at the startling conclusion that, to pass ordinary luminous discharges through gases, no particular degree of exhaustion is needed, but that the gas may be at ordinary or even greater pressure. To accomplish this, a very high fre-

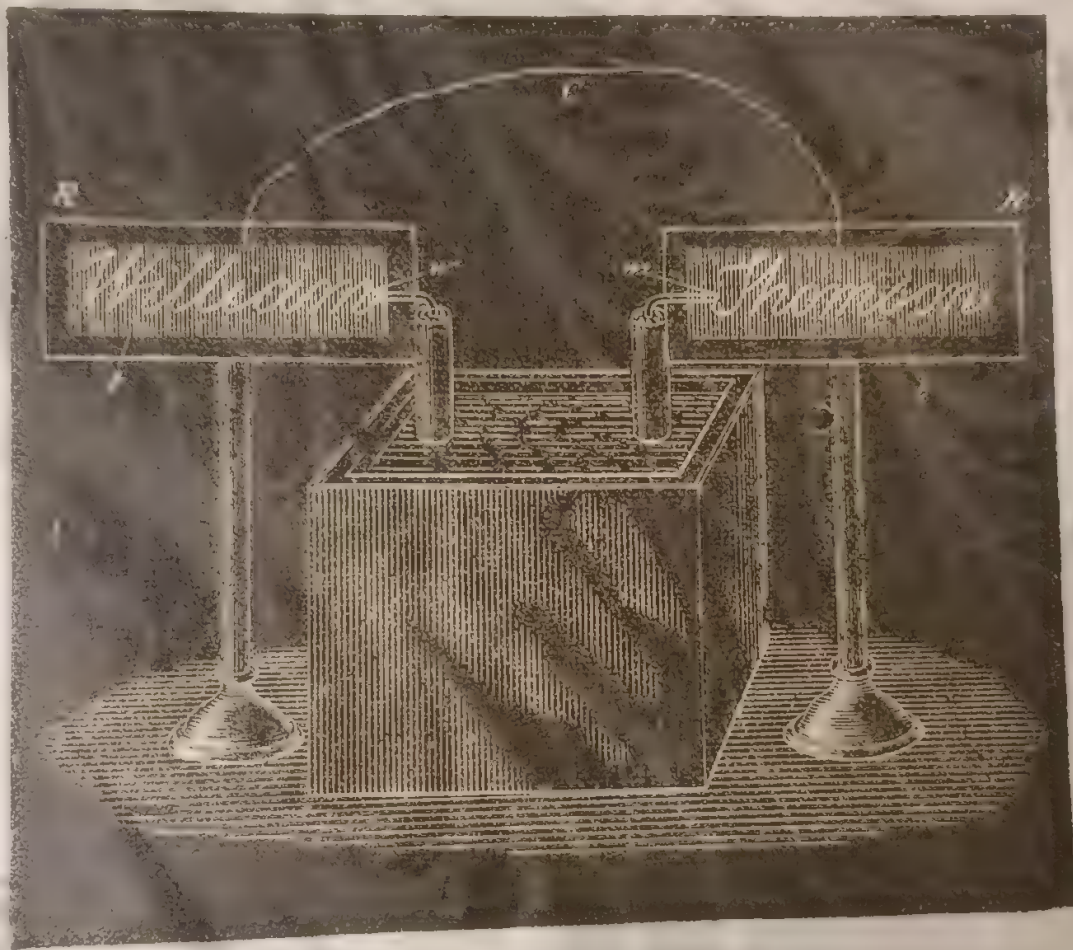


FIG. 9.—WIRES RENDERED INTENSELY LUMINOUS.

quency is essential; a high potential is likewise required, but this is a merely incidental necessity. These experi- teach us that, in endeavoring to discover novel

edges of the discs and spread. With this coil, when fairly 25 to 30 centimetres long, them no sensation is pro shock, jumps from the ter brought much nearer. If current is rendered inter there is a corresponding th the hand or other conduc still greater proximity to being caused to jump.

Among the many beau produced with such a coi which appear to possess s us to some conclusions of all difficult to produce i many other phenomena v than these here shown, b novelty.

Early experimenters duced by an ordinary lar ing plate separating the performed some experim tained, which were seen large coils, even if opera cies, are capable of pro largest coil ever made co cent display of streams disruptive discharge coi an idea, a coil such as plate of 1 metre in dia The best way to perfor thin rubber or a glass p row ring of tinfoil of ve a circular washer, the that of the ring, and the

name formed by them appears in brilliant letters.

It is perhaps preferable to perform this experiment with a coil operated from an alternator of high frequency, as then, owing to the harmonic rise and fall, the streams are very uniform, though they are less abundant than when produced with such a coil as the present. This experiment, however, may be performed with low frequencies, but much less satisfactorily.

When two wires, attached to the terminals of the coil,

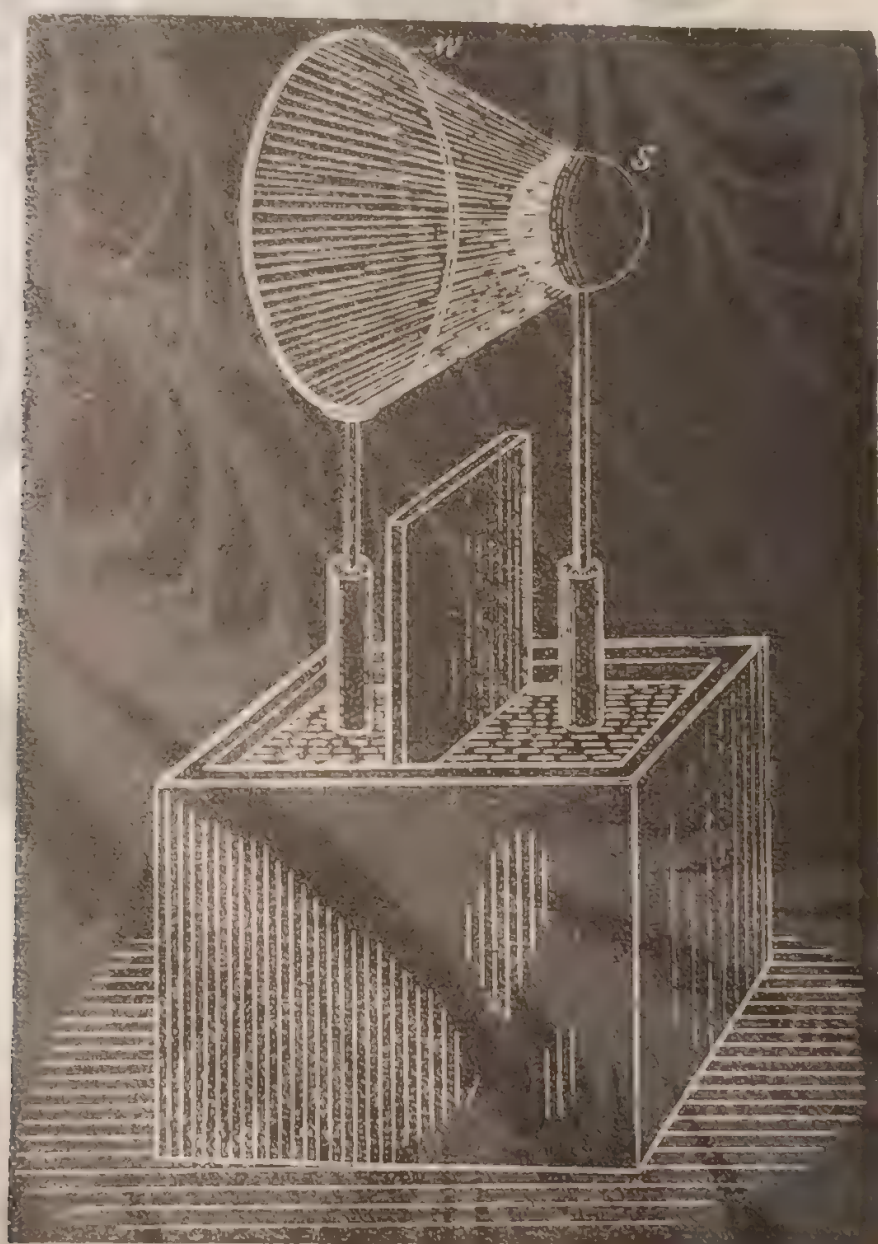


FIG. 8.—EFFECT PRODUCED BY CONCENTRATING STREAMS.

are set at the proper distance, the streams between them may be so intense as to produce a continuous luminous sheet. To show this phenomenon I have here two circles, *C* and *c* (Fig. 10), of rather stout wire, one being about 80 centimetres and the other 30 centimetres in diameter. To each of the terminals of the coil I attach one of the circles. The supporting wires are so bent that the circles may be placed in the same plane, coinciding as nearly as possible. When the light in the room is turned off and the coil set to work, you see the whole space between the

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A convenient way is to use an oil condenser of very small capacity, consisting of two small adjustable metal plates, in connection with this and similar experiments. In such case I take wires rather short and set at the beginning the condenser plates at maximum distance. If the streams for the wires increase by approach of the

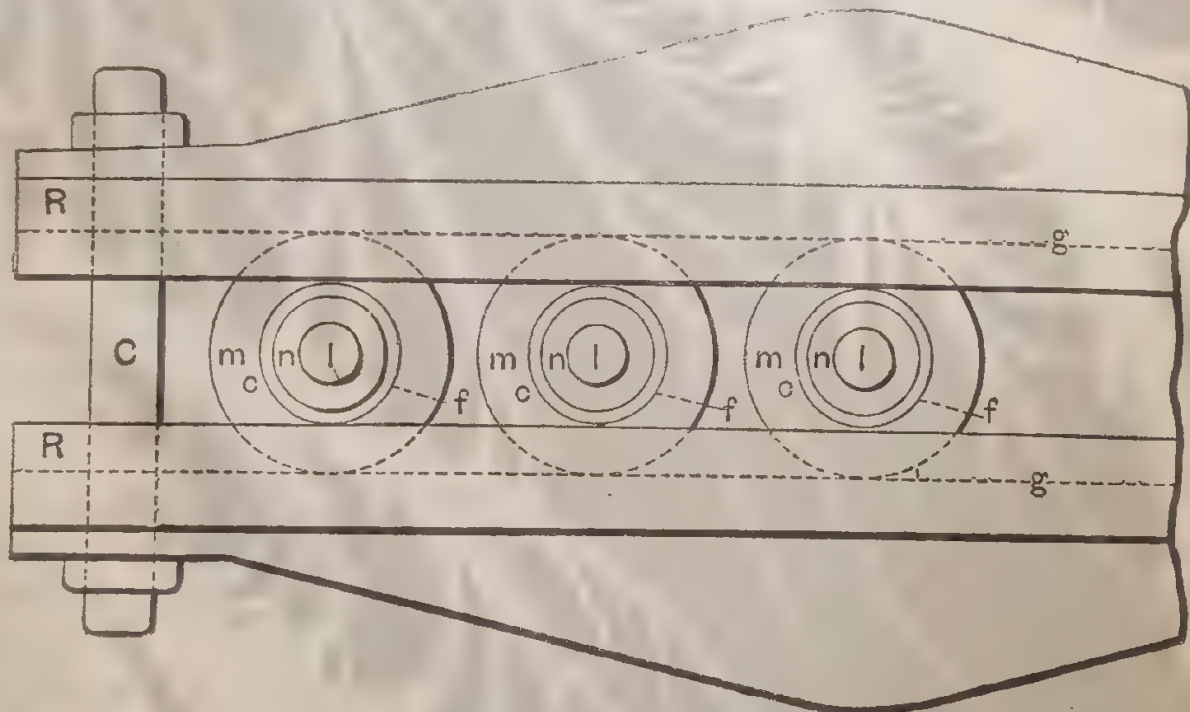


FIG. 7.—DISCHARGER WITH MULTIPLE GAPS.

plates, the length of the wires is about right; if they diminish the wires are too long for that frequency and potential. When a condenser is used in connection with experiments with such a coil, it should be an oil condenser by all means, as in using an air condenser considerable energy might be wasted. The wires leading to the plates in the oil should

choose the connection indicated diagrammatically in Fig. 5, as in this case the currents forming the arc are much more powerful, and the magnetic field exercises a greater influence. The use of the magnet permits, however, of the arc being replaced by a vacuum tube, but I have encountered great difficulties in working with an exhausted tube.

The other form of discharger used in these and similar experiments is indicated in Figs. 6 and 7. It consists of a number of brass pieces $c c$ (Fig. 6), each of which comprises a spherical middle portion m with an extension e below—

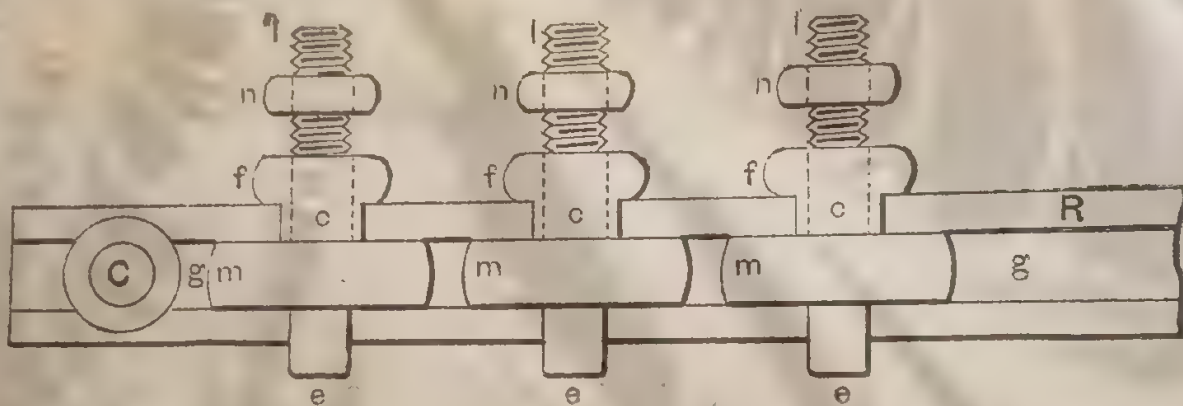


FIG. 6.—DISCHARGER WITH MULTIPLE GAPS.

which is merely used to fasten the piece in a lathe when polishing up the discharging surface—and a column above, which consists of a knurled flange f surmounted by a threaded stem l carrying a nut n , by means of which a wire is fastened to the column. The flange f conveniently serves for holding the brass piece when fastening the wire,

with such a coil as in using an oil condenser. The plates should be very thin, about one pound, and preferably extended conducting coils or ends, of jump from is used to diminish an electrostatic gain at once plates in oil are very small.

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all round. Where the oil is not specially needed, the space is filled with pieces of wood, and for this purpose principally the wooden box *B* surrounding the whole is used.

The construction here shown is, of course, not the best on general principles, but I believe it is a good and convenient one for the production of effects in which an excessive potential and a very small current are needed.

In connection with the coil I use either the ordinary form of discharger or a modified form. In the former I have introduced two changes which secure some advantages, and which are obvious. If they are mentioned, it is only in the hope that some experimenter may find them of use.

One of the changes is that the adjustable knobs *A* and *B*

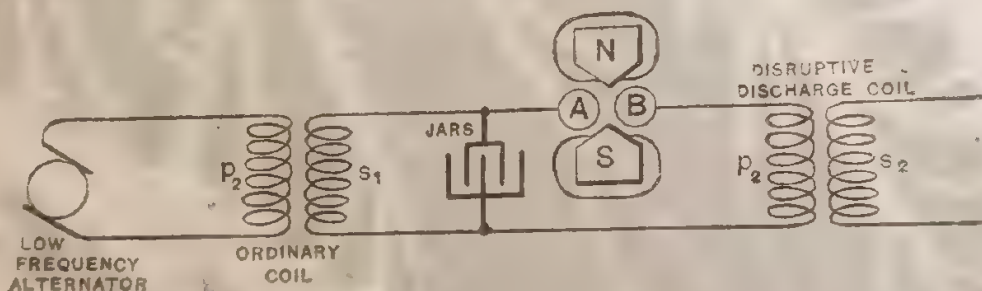


FIG. 5.—ARRANGEMENT WITH LOW-FREQUENCY ALTERNATOR AND IMPROVED DISCHARGER.

(Fig. 4), of the discharger are held in jaws of brass, *J J*, by spring pressure, this allowing of turning them successively into different positions, and so doing away with the tedious process of frequent polishing up.

The other change consists in the employment of a strong electromagnet *N S*, which is placed with its axis at right angles to the line joining the knobs *A* and *B*, and produces a strong magnetic field between them. The pole pieces of the magnet are movable and properly formed so as to protrude between the brass knobs, in order to make the field as intense as possible; but to prevent the discharge from jumping to the magnet the pole pieces

connected to the primary, but this is not always practicable.

The primary *P P* is wound in two parts, and oppositely, upon a wooden spool *W*, and the four ends are led out of the oil through hard rubber tubes *t t*. The ends of the secondary *T1 T1* are also led out of the oil through rubber tubes *t1 t1* of great thickness. The primary and second-

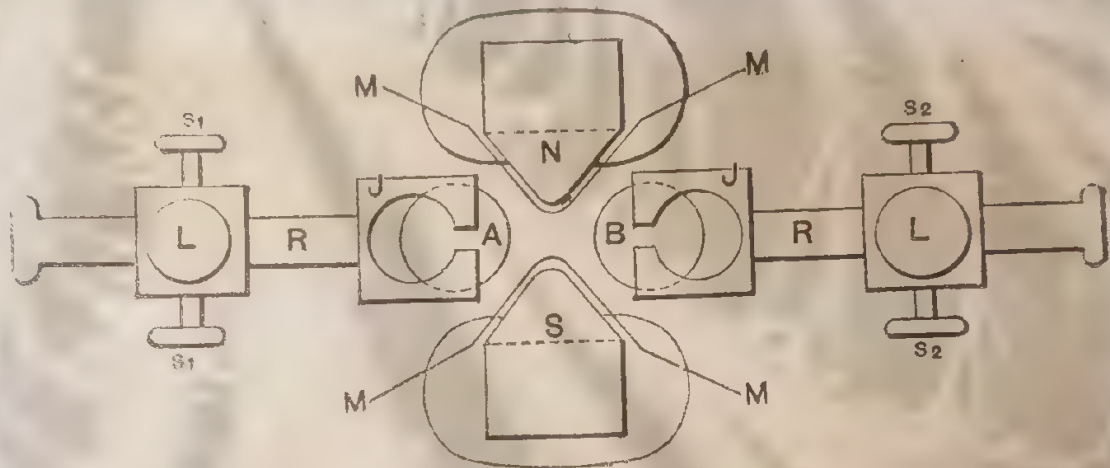


FIG. 4.—ARRANGEMENT OF IMPROVED DISCHARGER AND MAGNET.

ary layers are insulated by cotton cloth, the thickness of the insulation, of course, bearing some proportion to the difference of potential between the turns of the different layers. Each half of the primary has four layers, 24 turns in each, this giving a total of 96 turns. When both the parts are connected in series, this gives a ratio of conversion of about 1:2.7, and with the primaries in multiple. 1:5.4: but in operating with very rapidly alternating currents this ratio does not convey even an approximate idea of the ratio of the E. M. Fs. in the primary and secondary circuits. The coil is held in position in the oil on wooden supports, there being about 5 centimetres thickness of oil

in cases where the current and the keeping cool of the cases when the discharge are as soon as established thus starting the vibration. I have also used mechanical means to avoid the difficulties with the plan adopted was to establish at great speed a rim of iron fastened to a steel plate the employment of a multiplier produces an effect induction, capacity and are oscillations set up.

I will now endeavor to describe a method worthy of these discharges.

I have stretched and covered wires, each a centimetre in diameter, supported on insulating centimetres. I attach one of the wires to a battery of lights off in the whole surface in spite of the fact that the wires are even be very thick. under good condition and are intensely intense to allow of the production of the best results. To produce the best results just carefully the calculation of the length of the knobs and the length of the wires. To no result whatever take the wires at the cutting off first long ones as he approaches.

A convenient way of clamping the latter of two bolts through the end

In the use of principal advantages of dielectric strength greater when a of one, which air gap, and the of the metal into smaller much longer gauge in the putting between to obtain very small movements of Sir motive force

It should. distance is By taking an rough idea of to repeat an the knobs as I have been a any spark be knobs, and the temperature many arrangements often very preferably in when the cu

I may here with single surfaces we advantage

practical advantages, but these are not of sufficient importance to be dwelt upon.

The coil should be placed symmetrically to the metal

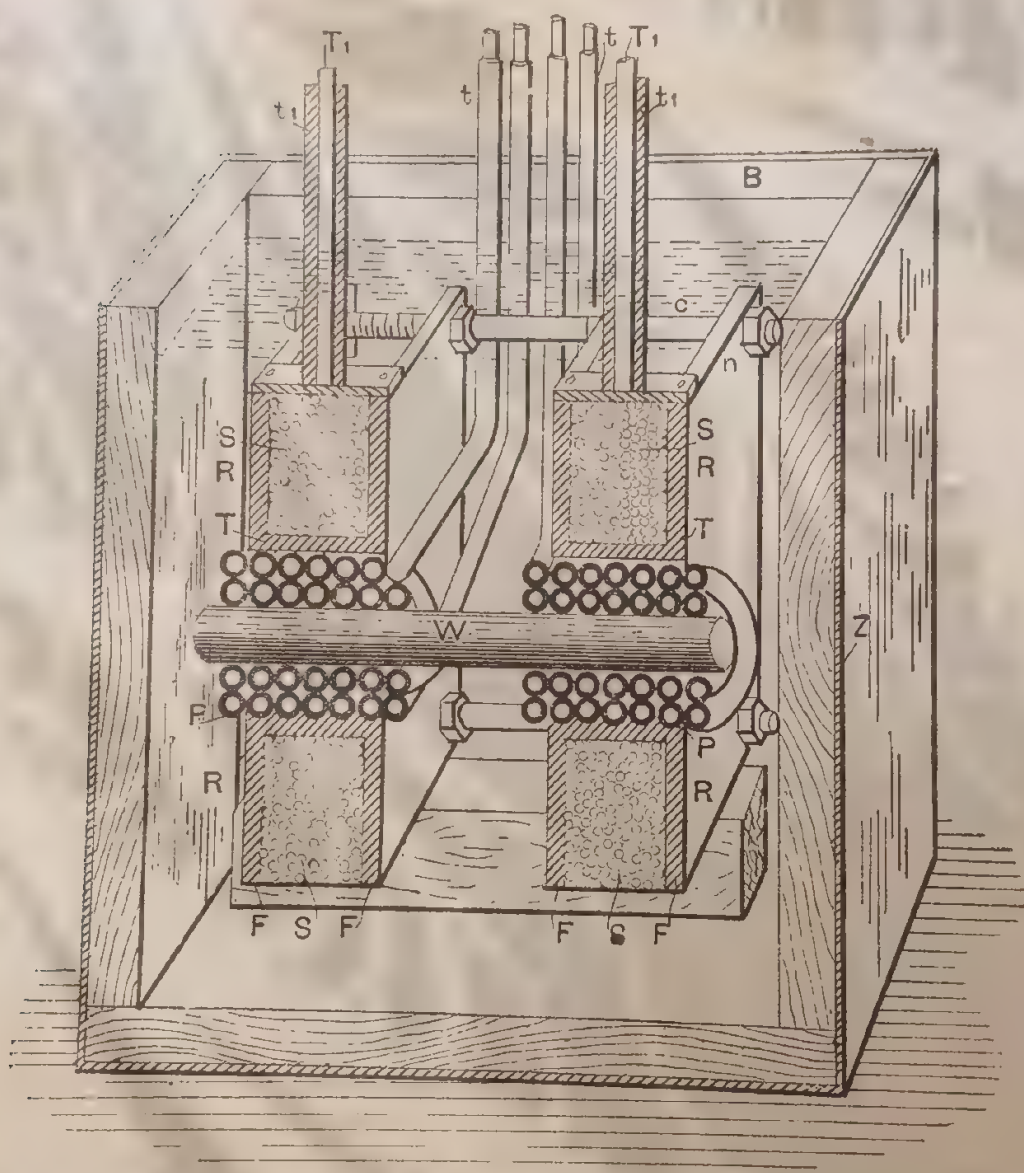


FIG. 3.—DISRUPTIVE DISCHARGE COIL.

cover, and the space between should, of course, not be too

angles to the line joining a strong magnetic field the magnet are moved protrude between the l as intense as possible; l jumping to the magne layer of mica, *M M*, of are screws for fastenin the screws is for large are screws for fixing in port the knobs.

In another arrangement charge between the ro in such case are insu polished brass caps.

The employment of vantage principally wh which charges the c very low frequency. fundamental discharge as to render the curre able for many experi then serves to blow ou as it is formed, and th quicker succession.

Instead of the magn employed with some preferably established (the knobs *a b* being away with), as in this steady, and is easily ad

When a magnet is e choose the connection as in this case the curr powerful, and the mag ence. The use of th arc being replaced by

surprise and interest him. Every one is familiar with the discharge of an ordinary coil; it need not be reproduced here. But, by way of contrast, here is a form of discharge of a coil, the primary current of which is vibrating several hundred thousand times per second. The discharge of an ordinary coil appears as a simple line or band of light. The discharge of this coil appears in the form of powerful brushes and luminous streams issuing from all points of the two straight wires attached to the terminals of the secondary.

Now compare this phenomenon which you have just witnessed with the discharge of a Holtz or Wimshurst machine—that other interesting appliance so dear to the experimenter. What a difference there is between these phenomena! And yet, had I made the necessary arrangements—which could have been made easily, were it not that they would interfere with other experiments—I could have produced with this coil sparks which, if the coil hidden from your view and only two knobs exposed, even the keenest observer among you would not distinguish from those of an influence machine. This may be done in many ways—for instance, by vibrating the induction coil which charges the condenser from an alternating-current machine of very low frequency, and preferably adjusting the discharge circuit so that there are no oscillations set up in it. We can obtain in the secondary circuit, if the knobs are of the required size and properly set, a more or less rapid succession of sparks of great intensity and small quantity, which possess the brilliancy, and are accompanied by the same sharp crackling sound, as those obtained from a friction or influence machine.

Another way is to pass through the primary circuits, having a common secondary, two currents of a slightly different frequency, which produce in the secondary circuit sparks occurring at comparatively long intervals. But, even with the means at hand this evening, I may succeed in imitating the spark of a Holtz machine. For this purpose

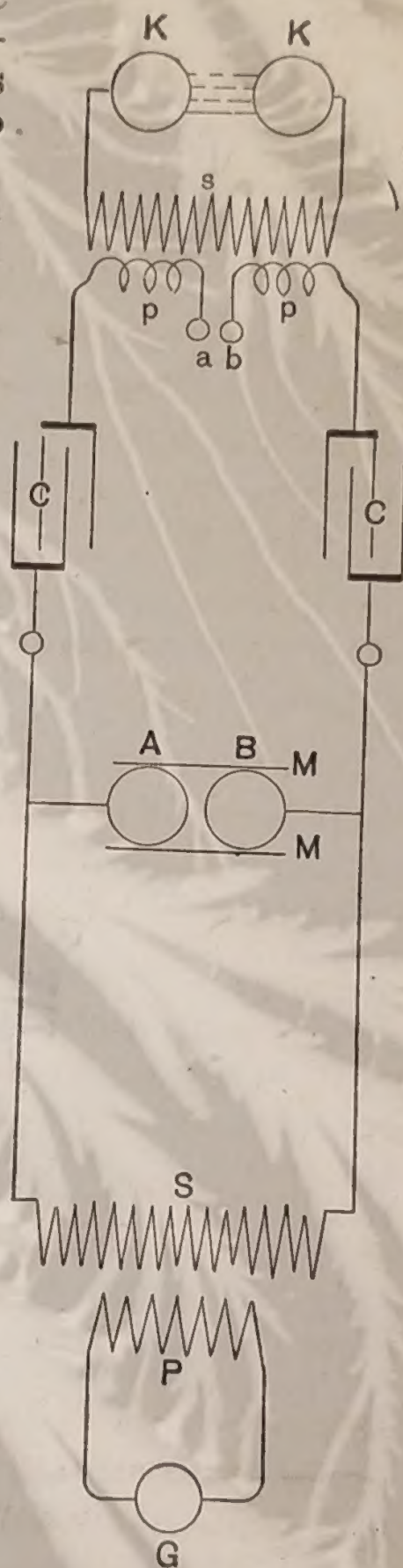


FIG. 2. — IMITATING THE SPARK OF A HOLTZ MACHINE

...tured to address so able an audience, that I have ventured to entertain you with that same old subject. Here in reality is the same apparatus, and here are the same phenomena, only the apparatus is operated somewhat differently, the phenomena are presented in a different aspect. Some of the results we find as expected, others surprise us, but

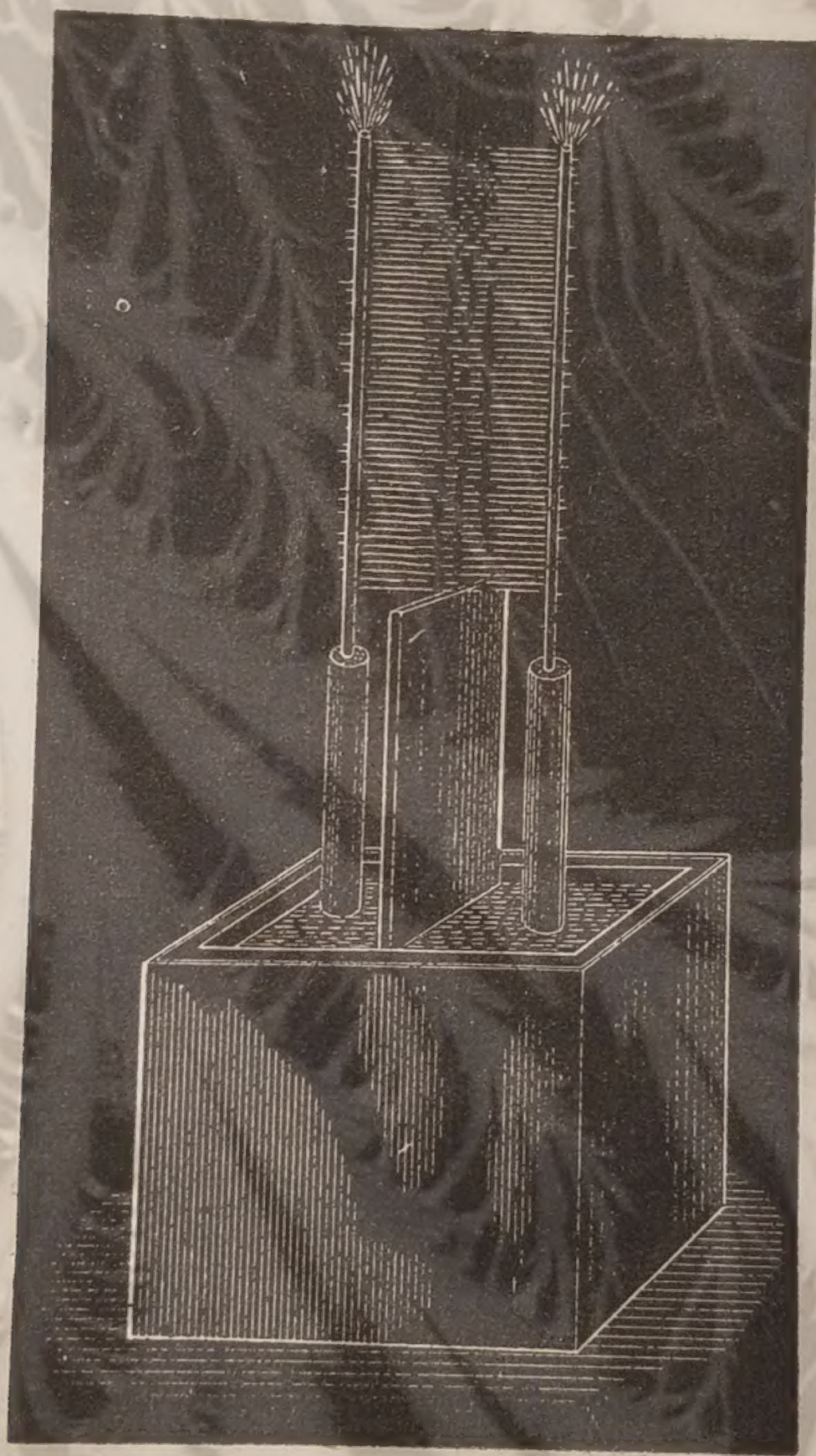


FIG. 1.—DISCHARGE BETWEEN TWO WIRES WITH FREQUENCIES OF A FEW HUNDRED THOUSAND PER SECOND.

all captivate our attention, for in scientific investigation each novel result achieved may be the centre of a new departure, each novel fact learned may lead to important de-

influence

Another two periods, common period, occurring with the in imitation pose I e charges periodically by it.

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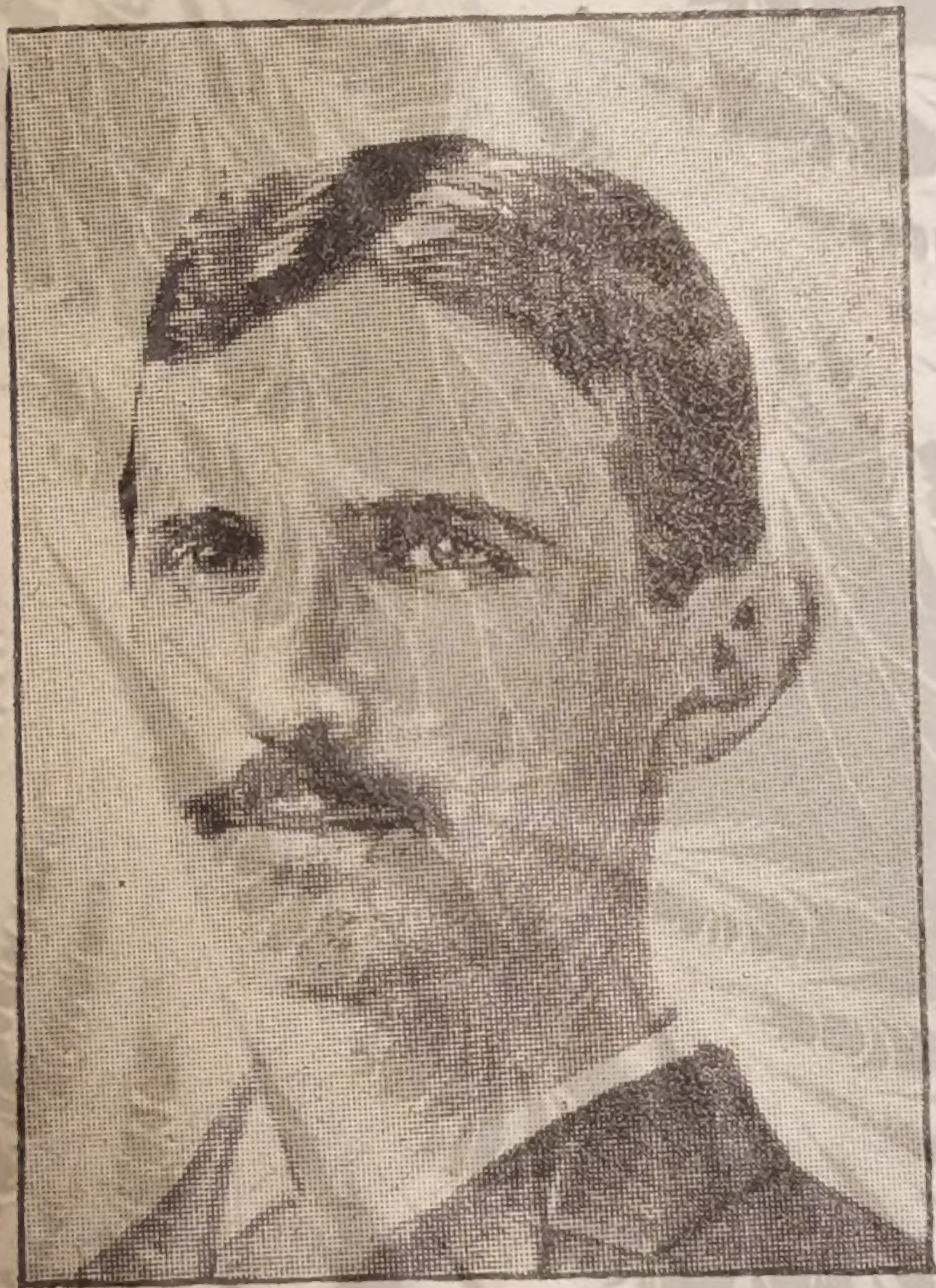
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